AD-A056 026 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 13/2
CAPACITY STUDIES OF GALLIPOLIS LOCKS, OHIO RIVER, WEST VIRGINIA--ETC(U)
MAY 78 L L DAGGETT , R W MCCARLEY
UNCLASSIFIED WES-TR-H-78-6 NL

1 OF 2
ADA
056026

TECHNICAL REPORT H-78-6

CAPACITY STUDIES OF GALLIPOLIS LOCKS OHIO RIVER, WEST VIRGINIA

by

Larry L. Daggett, Robert W. McCarley

Hydraulics Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

May 1978

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for U. S. Army Engineer District, Huntington
Huntington, West Virginia 25721

Destroy this report when no longer needed. Do not return it to the originator.

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Technical Report H-78-6	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): (6) CAPACITY STUDIES OF GALLIPOLIS LOCKS, OHIO RIVER, WEST VIRGINIA	5. TYPE OF REPORT & PERIOD COVERED: (9) Final report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): (10) Larry L. Daggett, Robert W. McCarley	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U. S. Army Engineer Waterways Experiment Station, Hydraulics Laboratory, P. O. Box 631, Vicksburg, Miss. 39180	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: U. S. Army Engineer District, Huntington, P. O. Box 2127, Huntington, W. Va. 25721	12. REPORT DATE: (11) May 1978
	13. NUMBER OF PAGES: 166
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office): (12) 172 p.	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DDC
RECEIVED
JUL 10 1978
B

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(14) WES-TR-H-78-6

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Gallipolis Locks and Dam
Inland waterways
Lock capacity
Locks (Waterways)
Tow lockage
Waterway simulation modeling

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Gallipolis Locks and Dam are located on the Ohio River at mile 279.2 and include a 600- by 110-ft main chamber and a 360- by 110-ft auxiliary chamber. As a result of increasing traffic and tow sizes, these locks have become a serious bottleneck to vessel movement along one of the major arteries of the United States inland waterway system. This report includes the results of an investigation to determine the physical capacity of the existing Gallipolis Locks, considering both operational and minor structural changes that could

CONT'

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

038 100 78 06 19 033

20. ABSTRACT (Continued)

possibly improve the locking efficiency at these locks. Several alternative operating policies, some requiring structural improvements, were analyzed and compared by employing the computerized TOWGEN/WATSIM (tow generator/waterway simulator) model package. Some proposed improvements were analyzed through the use of hand-computational and/or graphical techniques. The prototype data used in the investigation were collected and summarized through the Performance Monitoring System (PMS) of the Corps of Engineers Inland Navigation Systems Analysis (INSA) program. The report includes discussions of the data formats required by the model, calibration of the model, and analysis of model output. A number of capacity curves are presented to show the relation between increasing commodity tonnages, tow delays, and lock utilization. Lock capacity levels, in terms of tonnage per month and tonnage per year, are tabulated for convenient comparison of all potential operational and structural improvements.

Appendix A presents file identification codes for use with WATSIM, and Appendix B contains a comparison of October and December 1975 PMS data taken at Gallipolis Locks and Dam. Specialized terms used in the report are listed and defined in Appendix C, and PMS commodity codes are listed and described in Appendix D.

PREFACE

The study reported herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES), CE, for the U. S. Army Engineer District, Huntington (ORH). Computerized simulation models and hand-computational techniques were used to determine the capability of the Gallipolis Locks to serve future traffic levels by applying alternative operating policies and/or making relatively minor structural improvements. All of the currently proposed alternative means for increasing the efficiency of locking operations at the existing Gallipolis Locks are addressed in this report. ORH provided essential prototype data and assistance in analyzing and reducing these data.

The investigation was conducted by Dr. L. L. Daggett and Mr. R. W. McCarley of the Mathematical Hydraulics Division (MHD), under the general supervision of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Mr. M. B. Boyd, Chief of the MHD. The report was prepared by Mr. McCarley with technical guidance and input from Dr. Daggett. Mr. Thomas D. Ankeny, MHD, made minor modifications to the computerized lock simulation model used in this study and provided technical assistance in calibrating the models and interpreting model output. The investigation was coordinated with pertinent ORH personnel, who provided special assistance and consultation throughout its duration. Acknowledgment is made especially to Messrs. Alan Elberfeld, Ron Mead, David Weekly, and Ed Stone of ORH for their cooperation and assistance at various times throughout the investigation.

Director of WES during this investigation and the preparation and publication of this report was COL John L. Cannon, CE. Technical Director was Mr. Fred R. Brown.

CONTENTS

CONTENTS

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units of measurement as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
tons (2000 lb, mass)	907.1847	kilograms
degrees (angle)	0.01745329	radians

CAPACITY STUDIES OF GALLIPOLIS LOCKS, OHIO RIVER, WEST VIRGINIA

PART I: INTRODUCTION

Background

1. The Gallipolis Locks and Dam are located at mile 279.2 on the Ohio River with both chambers on the Mason County, West Virginia, side near Hogsett and across the river from Gallia County, Ohio, near Eureka. The locking facilities include a 360- by 110-ft* auxiliary chamber and the only remaining 600- by 110-ft main chamber in a system of 1200-ft-long lock chambers on the Ohio River, beginning with the New Cumberland Locks and Dam at mile 54.4 and continuing almost to the junction with the Mississippi River at Locks and Dam 50 and 51. Locks and Dam 50 and 51 are scheduled to be replaced by the 1200-ft Smithland Locks and Dam, which is currently under construction, and except for three to four months each year, river stages at Locks and Dam 53 are high enough for traffic to pass unrestricted over the navigable section of the dam. As a result of increasing traffic and tow sizes, the Gallipolis Locks and Dam have become a serious bottleneck to vessel movement along one of the major arteries of the United States inland waterway systems, especially affecting the movement of coal, a primary energy resource.

2. The data being collected to monitor the operation at Gallipolis and other locks clearly reveal that the main chamber is more heavily utilized with each succeeding year and many tows now experience excessive delays. For example, during the 12-month period from October 1975 through September 1976, the average utilization of the main chamber was 82.7 percent; i.e., the main chamber serviced vessels 82.7 percent of the total available time during this one-year period. Studies of the theory of queuing at service facilities such as locks generally confirm

---

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 5.

the fact that when utilization exceeds more than 70 to 75 percent, the average delay encountered by users increases at a very rapid rate with increases in traffic. High utilization of the Gallipolis Lock is caused in part by the many large tows (greater than 600 ft in length) traveling on the Ohio River as a result of the predominant 1200-ft locks and the more economical operation of such large tows. Specifically, 74.5 percent of the tows processed by the main chamber during the abovementioned 12-month period were large enough to require a double lockage. A double lockage requires considerably more time than two single lockages since these large tows must break into two components, one powered and one unpowered unit, to transit the 600-ft-long chamber. The average time for processing all tows during the 12-month period was 1 hr 23 min, whereas the double lockage size tows required an average processing time of 1 hr and 47 min each. This compares with an average single lockage time of slightly less than 34 min for tows that entered the chamber ready to lock without re-formation of the tow. The resulting long queues caused the delay of 73 percent of the tows passing during the period March through September 1976.

3. The existing Gallipolis Locks have also been a source of navigation problems because of their location on an inside bend, the orientation for approach channels, velocity currents in the river, and the design of the approach walls. At times the entry of downbound tows into the lock is made particularly hazardous by the river currents that pull tows toward the gates of the dam during periods of high flows. The unsafe conditions in the upper approach therefore prolong tow entries and exits and often require extra lockmen to assist entering tows by handling ropes attached to the bow of the tow.

4. Certain factors discourage the use of the 360- by 110-ft auxiliary chamber by most tows. At present, the auxiliary chamber is primarily used by small tows, light boats, and pleasure craft. Multiple lockage tows would require as many as six lockages in the auxiliary chamber, whereas the same tow could transit the main chamber as a double lockage. The processing of multiple lockage tows through the auxiliary chamber can also create unsafe approach and exit conditions for other

tows using the main chamber. In addition to its small size, the lack of adequate guide walls or guard walls to assist tows while they enter the auxiliary chamber and recouple after lockage has contributed to the low utilization of this facility. The Performance Monitoring System (PMS) data indicated that the auxiliary chamber was utilized only about 16 percent of the time during a 12-month period.

5. The commodity tonnages passing through Gallipolis Locks are predicted to increase steadily through 1985. Detailed commodity growth projection studies have been completed through the year 1981 only. These studies predict traffic tonnages through Gallipolis Locks to be about 52.8 million tons in 1980, a 43 percent increase from the 36.9 million tons reported in 1976. The traffic volume could reach over 63 million tons by 1985, but such figures are currently based on the extension of growth histories and the projection studies completed through 1981. The number of tows and barges required to transport tonnages of such volumes could very well exceed the locking capacity of the current facilities.

6. Based on this and other evidence, the U. S. Army Engineer Waterways Experiment Station (WES), CE, was requested to initiate a study to determine the capacity of the existing Gallipolis Locks and to consider means for improving locking efficiency. These studies provide essential knowledge required in planning for the proper expansion of locking capabilities at Gallipolis Locks and Dam to meet the future demands of waterborne traffic.

Objectives

7. The study's primary objective was determination of the capacity of the existing Gallipolis Locks, considering both operational and minor structural changes that could improve locking efficiency. A wide range of potential improvements was available for consideration, varying from simple policy changes that would yield only small improvements in locking efficiency to improvements that would require capital investments and/or operating expenditures with anticipated large improvements in

operating efficiency. All potential improvements were aimed at one or more of the following:

a. Increasing the degree to which the lock chamber is filled with tows and other vessels for each lockage.

b. Decreasing the time the lock is waiting for tows to enter or exit, yielding greater utilization of the auxiliary chamber.

c. Allowing optimum operation of the filling and emptying system.

d. Decreasing the time lost due to double lockage; e.g., the Ready-to-Serve operating policy to be explained later eliminates all double lockages.

Scope

8. The scope of this study, which includes a comparative analysis of proposed alternative means for increasing locking efficiency at Gallipolis Locks, was discussed and agreed upon during meetings held at the U. S. Army Engineer District, Huntington (ORH), and Office, Chief of Engineers, in September 1976. A computerized waterway simulation model was used as the primary tool for determining the tonnage capacity of the locks and expected delays associated with alternative operating policies and projected increases in waterway traffic. Certain minor modifications to the model were necessary to include interferences with the movement of traffic caused by entering and exiting tows occupying the entire approach channel. Projected tonnage levels through the year 1985 were provided by ORH.

9. The following four alternative operating policies were simulated directly by the model to determine their respective effects on the capacity of Gallipolis Locks and Dam and the expected delays should such policies be implemented:

a. First In-First Out (FIFO) Unrestricted

b. 1 Up-1 Down (1U1D) Unrestricted

c. 3 Up-3 Down (3U3D) Unrestricted

d. FIFO Ready-to-Serve

These operating policies are discussed in detail later in this report.

10. This investigation also includes an analysis of the benefits of switchboat operations, coupled with minor structural modifications and additions, such as the construction of additional mooring cells. Simulation model runs were made for switchboat operations in the upper pool only and also for switchboat operations in both the upper and lower pools. Comparison studies considered the effects of using switchboats in the upper pool and extending the center guard wall in the lower pool so tows could recouple on it while the lock is turned back to process another tow. An analysis was also made of a proposal to use switchboats in the upper pool and extend the lower landward guide wall so that tows could recouple there rather than inside the main chamber. Extension of the lower guide wall rather than the lower center guard wall, however, would cause tows recoupling there to block the entry and exit of other tows using the auxiliary chamber.

11. The study includes an evaluation of the effects of approach channel interference caused by entering/exiting vessels and unpowered tow sections secured to the guide walls during double lockage operations, and the impact on lock capacity of scheduling tows for use of the main and auxiliary chambers to minimize this interference. The scope also includes an analysis of PMS data to determine the effects of dredging in the lower pool, high versus normal flows at the locks, and adequate clearance by tows of the lock's water intake and outlet areas.

Approach

12. The approach to making the subject study was similar in part to that reported in WES Miscellaneous Paper H-77-1.[1] In general, a simulation modeling approach based on the TOWGEN/WATSIM (tow generator/waterway simulator) model package was used to generate delay, tonnage level, and utilization functional relations that can be used to determine capacity and economic benefits. The modeling involved only the Gallipolis Locks and the upper and lower pool areas. The available PMS data were the basic source of model input data with additional data furnished by the sponsor when requested. Fleet characteristics and

commodity/equipment relations were derived from the PMS data. An analysis of time variations of the commodity movement did not reveal any significant seasonal variations. Locking component (entry, chamber processing, exit, etc.) times were also obtained from PMS data. The current fleet characteristics were used as the basis for most of the analysis on the assumption that most tows are now made up in the most efficient barge configuration for transiting the Ohio River system of 1200-ft locks. This assumption is supported by the large number of double lockage size tows, nearly 75 percent, passing through the main chamber. Output from the simulation model runs were plotted to depict the increases in delay times with increased tonnages, and increases in tonnage and delays with increased lock utilization.

13. The approach to the accomplishment of this study's multi-objective scope also included the use of simple hand-computational and graphical techniques to analyze some of the proposed alternatives presently not within the scope of the simulation model. In addition, selected portions of the PMS data were processed using a computer to study lockage times of tows under varying conditions at the lock, e.g., lockages during periods of high water versus those during low flows.

PART II: THE TOWGEN/WATSIM MODEL

Brief Description of the Simulation Model: TOWGEN/WATSIM

14. The basic simulation model used in the Gallipolis Locks and Dam capacity study was originally developed for the Corps of Engineers by Pennsylvania State University and extensively modified and expanded by WES during the past several years. The model is described in detail in an unpublished WES report,[2] a copy of which may be borrowed for official purposes from the WES Mathematical Hydraulics Division. Further information on the use of this model for determining the capacity of locks is given in WES Miscellaneous Paper H-75-9,[3] presented at the First International Waterborne Transportation Conference in October 1975.

15. The model consists of two separate computer programs called TOWGEN and WATSIM. A brief description of how these programs simulate traffic movement along a waterway and through locks is given in Reference 1, but is repeated here for the reader's convenience.

16. TOWGEN is a tow generation program that combines the commodity movement pattern and the tow equipment and flotilla description to develop a randomly generated list of simulated tows to be moved through the waterway system or lock being tested. This tow list contains a description of the characteristics of each tow, the origin and destination of each movement, and the time of entry into the system. The tows are generated so that all the commodity movements required are started during the simulated time period. The tows are generated in such a manner as to assure that a balance of equipment exists throughout the system; i.e., empty barges are moved to locations where they are required for the movement of goods.

17. Through the use of TOWGEN, the towing industry's requirements or demands for use of the waterway being analyzed may be developed for input to the waterway simulator, WATSIM. WATSIM reads the list of tows generated by TOWGEN and inserts the simulated tows at the appropriate

time into the traffic flow at their points of origin along the waterway. WATSIM then moves each tow from its originating point to its destination in a series of steps covering each segment of the simulated waterway. As each tow is moved, statistics concerning the trip and the waterway facilities used are accumulated. These statistics provide a measure of the waterway's effectiveness in handling the traffic demands placed upon it and the time required to transit the waterway between various points. This transit time may then be translated into the cost of transport by application of tow operating costs per unit of time.

18. The simulation process used by WATSIM is called event modeling. The various activities required to accomplish the task being modeled are represented by a series of events. Because the time to accomplish these events, and hence the entire task, is the critical parameter, each event is represented by WATSIM as a period of elapsed time. These times are stochastic, not deterministic, and are described by frequency distributions and functional representations. The modeling process thus involves the logical combination of the events required to move a tow from its origin to its destination, accounting for the interaction of the tows at commonly shared facilities.

19. Simulation modeling uses simplified representations of the real-world activities involved in the modeled situation. The degree of simplification allowed in the description of any event depends upon the purpose of the simulation and significance of that event to the process being simulated. WATSIM has been primarily used in the past to evaluate lock replacement or expansion requirements and scheduling; therefore the modeling of these events is quite detailed and well developed.

WATSIM Modifications

20. The WATSIM program was modified for specific application to the Gallipolis Locks and Dam study. Since the entrance conditions of the lock are such that entering vessels must occupy the entire approach channel, the program had to be expanded to include the resulting interference to lock operations in the computational logic. Before

modification, the latest WATSIM version simulated the operations at two chamber locks such that tows using either chamber were not concerned with whether another tow was using the approach channel to enter or exit the adjacent chamber. The program was reviewed and modified to consider interferences between tows.

21. As described in Reference 1, modifications were also made to the WATSIM program during the Winfield Locks and Dam capacity study to enable the printing of all model output required for capacity analysis on one table (Table 13, Composite Lock Statistics) and to more accurately compute the utilization of the lock chambers. The data in the new Table 13 (Figure 1) now includes the total time (in minutes) during which interference between entering and exiting tows occurred in the approach channels from the beginning of the simulation to the sample period time. Also shown is the number of tows delayed due to the interference. Delay times due to interference from entering and exiting tows in the approach channel were generally insignificant compared with the total simulated delay times experienced in future years.

22. Other data contained in Table 13 are self-explanatory. As shown in Figure 1, the upper portion of the table presents useful data for each chamber, and the lower portion displays other important data for both chambers combined. The Run Identification Number shown in the upper left corner of Table 13 ("0008M01GFR88" in Figure 1), which is explained in Appendix A, simulation time (47,520 min from time zero in the figure), and the number of chambers and locks (2 and 1, respectively, as shown) are included as header information on each printed page. All output contained in the printed table is also written to a file at the central computer site. The program is designed to store the data produced for each intermediate output simulation time (every 4,320 min for a total of 10 output sets). Such files are readily available for use by post-WATSIM processing programs to provide data for various analyses. A short program is used to punch these data on cards so that the files at the central computer site can be purged for use by others. The first simulation period of 4,320 min is a warm-up period to allow the model to achieve steady state conditions before usable sample data

ER=001
000AM01GERBB 47520 2 1

TABLE NUMBER 13
COMPOSITE LOCK STATISTICS

		GALLIP CHMB A	GALLIP CHMB B
NO. OF SINGLE LOCKAGES	DN	4	50
	UP	5	52
	TOTAL	9	102
NO. OF DOUBLE LOCKAGES	DN	225	124
	UP	256	116
	TOTAL	481	240
NO. OF TRIPLE LOCKAGES	DN	0	0
	UP	0	0
	TOTAL	0	0
NO. OF SETOVER LOCKAGES	DN	47	20
	UP	58	15
	TOTAL	105	35
NO. OF MULTI-TOW LOCKAGES	DN	0	0
	UP	0	0
	TOTAL	0	0
NO. OF OPEN-PASS LOCKAGES	DN	0	0
	UP	0	0
	TOTAL	0	0
TOTAL NO. OF LOCKAGES	DN	276	194
	UP	319	183
	TOTAL	595	377
TOTAL NO. OF BARGES	DN	2689	944
	UP	3107	925
	TOTAL	5796	1869
TOTAL TOW PROCESSING TIME	DN	17956	11155
	UP	22824	11033
	TOTAL	40780	22188
PERCENT UTILIZATION	DN	43.90	28.94
	UP	56.05	28.00
	TOTAL	99.94	56.94
CHANNEL INTERFERENCE	TOTAL	287	522
NO. OF INTERFERRED TOWS	TOTAL	41	55

		GALLIP
TOTAL NO. OF TOWS	DN	470
	UP	502
	TOTAL	972
NO. OF MULTI-LOCKAGE TOWS	DN	0
	UP	0
	TOTAL	0
NO. OF TOWS DELAYED	DN	441
	UP	472
	TOTAL	913
TOTAL NO. OF LOADED BARGES	DN	1066
	UP	3390
	TOTAL	4456
TOTAL NO. OF EMPTY BARGES	DN	2567
	UP	642
	TOTAL	3209
TOTAL TONNAGE	DN	1442845
	UP	4943465
	TOTAL	6386310
TOTAL DELAY TIME (MIN)	DN	348977
	UP	391468
	TOTAL	740445
AVG DELAY FOR TOWS DELAYED		811
AVG DELAY FOR TOWS PASSING		761

Figure 1. Example of WATSIM output composite lock statistics (Table 13)

is produced. Statistics on tows processed by the model during this period are not retained on file for analysis.

Computer Facilities Used

23. The CDC 6600 computer facilities located at the U. S. Army Mobility Engineering Research and Development Center (MERDC), Ft. Belvoir, Virginia, were used to make all simulation runs. Access to this computer system was made through the COPE 1200 terminal located at WES.

PART III: ANALYSIS OF GALLIPOLIS LOCKAGE DATA

General

24. One of the major efforts in the Gallipolis Locks capacity study involves the application of the available TOWGEN/WATSIM simulation model described earlier to analyze the impact of various potential lock operating policies at various projected traffic volumes. The first step in such a study is to develop the required input data for the simulation model and to verify that the simulation model will reproduce the observed occurrences at the locks.

25. The prototype data collected under the PMS program during the months of October and December 1975 were used to develop the input data for the model. The December 1975 data were used primarily to analyze the physical characteristics of tows serviced by Gallipolis, commodity types and quantities, and directional movements. Lockage component time distributions were based on the October 1975 data, which had been processed and listed in a more usable format than the December data. The December data were available at an earlier date than the processed October data and therefore were utilized to prevent delay of the study. A comparison of the data for these two months was made to determine if there was a significant difference in any of the parameters reported. The results of this analysis, reported in Appendix B, revealed no significant differences in the lockage data.

Description of the PMS Data Used

26. As mentioned above, the December 1975 Gallipolis lockage data, available when work on this project began, were analyzed first. These data consisted of a line item for each tow, sorted first by the recorded barge type (R, J, I, etc.), then by number of barges in each tow. In addition to the data on which the sorting was keyed, the December data also included the following:

a. Assigned vessel number

b. Horsepower

c. Commodity code

d. Tonnage by barge type and commodity

e. Computed average barge loading

f. Computed average barge length

g. Lockage type

h. Flotilla length and width

i. Direction of travel

27. The October 1975 PMS data used to determine the lockage component time distributions were formatted and sorted especially for this purpose. The time each tow required to perform some lockage function, e.g., enter chamber or exit, was computed, and all times for a given lockage component were listed in increasing order to establish frequency distributions.

Determination of Predominant Barge Types Using Gallipolis

28. The computed average barge loadings and lengths in the Gallipolis data, not available for the Winfield capacity study, proved very helpful by reducing hand calculations and providing a readily available check for use in classifying barge types. However, all of the December data could not be immediately sorted and accumulated because of the absence of towboat lengths. After these lengths were obtained from the U. S. Coast Guard, the barge types recorded as Regular (R) and Jumbo (J) barges were spot-checked by computing average barge lengths, and the average integrated barge lengths were determined by hand calculations.

29. The lock operators classified several of the barges as Tanker- (T) type barges. This was probably an invalid classification since, by definition, T-type barges are self-propelled tankers, normally not found on the innermost parts of the inland waterway system. Accordingly, the T-type barges were simply reclassified as Integrated- (I) type barges. In addition, a small number of barges were recorded as Super Jumbo (S). Again, this was probably an incorrect classification since the PMS criteria established S-type barges as 40-ft wide. Since the width of these

barges did not compute to be 40 ft, such barges were reclassified as I-type barges also.

30. The physical makeup of tows using Gallipolis is complex. Of the approximately 496 tows passing through the lock in December 1975, 122 of them were pushing more than one barge type. This is referred to as "a mixed barge tow" and each one was classified into one of the selected tow type categories where possible. This was usually based on the predominant barge type within the flotilla. I-type barges were also difficult to categorize because of the wide variety of sizes. An average integrated barge size had to be determined for each tow pushing this type of barge. These barges were then grouped by average length and where significant tonnages were involved, identified as to whether the commodity being transported was petroleum or chemical. The empty tows were also classified as either chemical or petroleum by consideration of the predominant commodity transported by each individual pusher boat.

31. After analysis of the results of the work described above, nine predominant barge types were established for Gallipolis, as shown in Figure 2. Based on the analysis and classification of the mixed barge tows, 359 of the 496 tows locked during December 1975 were

Barge Type	Description
R BULK	175' x 26' Open & Covered Hopper
J BULK	195' x 35' Open & Covered Hopper
J TANK	195' x 35' Tanker
I 150	150' x 52' Integrated Petroleum & Chemical Barges
IP 200	200' x 52' Integrated Petroleum
IC 200	200' x 52' Integrated Chemical Barges
IP 250	250' x 54' Integrated Petroleum Barges
IC 250	250' x 54' Integrated Chemical Barges
I 300	300' x 54' Integrated Petroleum & Chemical Barges

Figure 2. Predominant Gallipolis barge types (average dimensions indicated for I-type barges; approximate dimensions for other barge types)

transporting either all or predominantly R- and J-type barges. The remaining tows were placed into one of the six I-barge categories.

Current Lockage Types at Gallipolis Locks and Dam

32. The lockage types--single, double, setover, etc.--for tows of various sizes and types were next determined. Eight standard tow types were established, one for each different barge type, with the exception of J BULK and J TANK barges, which are included in the same tow type since they are of the same length and are quite often mixed. Information on how the tows were configured as they approached the lock was obtained from the December lockage data for each tow type and for the different size tows within the tow types. Using this knowledge, coupled with the lock chamber sizes of 600 by 110 ft and 360 by 110 ft, the lockage types normally expected were determined as shown in Table 1. As indicated in Table 1, expected lockage types for the eight standard tow types ranged from multiple tows to as high as six cuts if some of the large tows used the auxiliary chamber. However, the WATSIM model input data was formulated to discourage such large tows from using the small chamber. This was accomplished by assigning large "penalty times" to the estimated lockage times for tows requiring more than a single lockage in the auxiliary chamber, thereby inducing these tows to select the main chamber for lockage as they presently do. The multiple lockage types shown in Table 1 indicate that some tows would be small enough for more than one to be locked together in a single chamber operation. The pusher lengths shown are average representative lengths for establishing standard overall flotilla lengths.

Tow Size/Horsepower Frequency Distribution (Tow Codes)

33. The tow size/horsepower frequency distributions, referred to in the simulation procedure as "tow codes," are presented in Table 2 for each of the eight tow types. These codes are produced by a program, UTILITY I, for direct input to TOWGEN and WATSIM. The numbers in the

body of Table 2 under the horsepower ranges indicate the percentage of the total tows of each type having a specific horsepower and number of barges. For a capacity study of only one lock facility (such as Gallipolis Locks and Dam), the TOWGEN model uses this information to generate the proper number of tows of the various sizes within each tow type and WATSIM uses the tow type and tow size information to determine the proper lockage type--single, double, setover, knockout, etc. The horsepower data would be required only for navigation systems studies involving two or more locks and tow travel between them. As indicated earlier, the mixed barge tows were classified according to the predominant barge type and included in the counts. When no dominant barge type was present in a mixed barge tow, that tow could not be included in the counts.

34. The tow codes shown in Table 2 are based on the December 1975 PMS data taken at Gallipolis but the percentages are not exactly as reported in all cases. Some minor adjustments were made to the percentages in order to calibrate the WATSIM model more precisely. The tow codes shown in Table 2 were used to obtain the best calibration run results.

Detailed Barge and Commodity Data

35. Additional statistics were accumulated to determine the load characteristics of the nine predominant barge types. Each commodity type passing through Gallipolis Locks and Dam had to be assigned to one of the nine barge types. As shown in Table 3, the number of barges and the tonnages carried by each barge type are given for each commodity. PMS commodity codes were used to indicate commodity types (see Appendix D). Total barges and commodity tonnages are shown for each barge type, and the grand total tonnage for the month of December 1975 is given in the lower right corner of the table. In addition, the average load per barge for each barge type, as required for input to the model, is given at the bottom of the table.

36. Table 4 presents a summary of the barge types that moved the

six main commodity groups through Gallipolis. The left portion of the table (first 3 columns) shows each commodity group broken down by PMS commodity code and the barge types that transported each commodity. The last four columns consolidate the commodity tonnages by barge type and indicate the percent of each commodity group transported by each barge type.

37. To aid in the accurate calibration of the simulation model, the directional movement of commodities during the month of December 1975 was determined as shown in Table 5. These data were obtained by tabulating the commodity type and tons by direction (up or down) for each loaded tow. These data revealed that the commodity movements were predominantly upbound, as indicated by the percentages given in the three columns on the right in Table 5.

Tow Processing Times at Gallipolis Locks and Dam

38. The data obtained from an analysis of the October 1975 tow processing times reported in PMS are summarized in Table 6. The average lockage component times and frequencies of occurrence are given for the main chamber on the first page, immediately followed by the same data for the auxiliary chamber on the next page. Brief comments concerning the lockage components listed in Table 6 follow.

Single lockages, up and down

39. Each tow requiring only one standard lockage (filling or emptying of the lock chamber once) with no reconfiguration of the tow was placed into this category and separated by the tow's travel direction (up or down). The percent of single lockages occurring in the main and auxiliary chamber was about 13 and 24 percent, respectively.

Double and double knock-out lockages, up and down

40. This category accounted for 76 percent of the lockages in the main chamber and 21 percent in the auxiliary. A double lockage is the lockage of a tow larger than the lock via two distinct chamber operations. A double knockout is required when one cut of a double lockage

must be a knockout type lockage to permit passage of the tow in only two lockages.

Triple or over standard,
knockout, setover, and jack-
knife lockages, up and down

41. No lockages of these types presently occur at Gallipolis. An assumption made at the outset of this study was that the fleet's current physical characteristics would remain constant in future years. This assumption is considered valid since many tows are now configured for transit of the predominant 1200-ft locks on the Ohio River. Though lockages of this type are not expected in the main chamber, a single approximated time for each direction is indicated for the auxiliary chamber since such lockages would be expected to occur in that chamber with increasing traffic in future years.

Single knockout and set-
over lockages, up and down

42. Only 11 percent of the October 1975 lockages in the main chamber were of these types; however, over 32 percent of the auxiliary chamber lockages were knockouts and setovers. A knockout lockage is a lockage where the towboat alone is separated from its barges to be repositioned in the lock for service. A setover lockage occurs when a towboat and one or more of its barges are separated from the remaining barges to be repositioned in the lock for service.

Fly and exchange
entries, up and down

43. The type of entry made by each tow is indicated in the PMS printout as a fly, exchange, or turnback approach. The fly and exchange type entries were grouped together since both are considered to be long entries, i.e., entries that involve transit of the approach channel.

Turnback entries, up and down

44. Such entry types were grouped separately because of the shorter entry times normally involved. A turnback entry occurs when two vessels traveling in the same direction are locked sequentially, allowing the second tow to maneuver close to the lock entry gates

while the first tow is being serviced. Thus, the second tow can normally position itself to make a turnback (or short) entry.

Exits, up and down

45. Only the exit times of single lockage tows were compiled since the WATSIM-defined exit times of tows that required other lockage types could not be computed using the PMS data. The PMS exit times for these other lockage types include the time for recoupling the tow for transit in the river. The use of single lockage tow exit times is considered to be a valid alternative since almost all normal exit times are relatively short, regardless of tow size or horsepower.

Turnback (or swing-around)

46. Average times required to fill or to empty the lock and their frequencies of occurrence were determined for each chamber.

Open pass lockages, short and long, and tow break and remake

47. These lockage components are not applicable at this time to the Gallipolis capacity study.

Multiple entries, up and down

48. This involves the entry time required by two or more relatively small tows that are to be processed in a single lock operation. Because of the lack of data, fly and exchange entry times were used to approximate multiple tow entry times. This should have no effect on the model results since multiple tow lockages occur very infrequently at Gallipolis.

Multiple tow lockages, up and down

49. Again, since no data were available, standard single lockage times and distributions were employed for modeling purposes in lieu of actual multiple tow lockage times.

Multiple exits, up and down

50. Single lockage tow exit times were used for this data element also.

Grouping of Lockage Component Times

51. The lockage component times, computed using the PMS data, were

placed in groups according to their magnitude, the average of each time group computed, and a frequency distribution developed. From these data, the frequency of occurrence was computed on a percentage basis as shown in Table 6. Further definitions of the lockage components listed above are given in Appendix C.

PART IV: TOWGEN/WATSIM MODEL CALIBRATION

General

52. This part of the report discusses the calibration of the computerized simulation model (TOWGEN/WATSIM IV) for use in the Gallipolis Locks and Dam capacity study. Based on a comparison with the extensive lockage statistics now available through the PMS, the model very closely reproduces observed lockage operations at Gallipolis. The statistical parameters of significance used in comparing the simulation model output with the prototype data provided by PMS are presented in Table 7 for both chambers as a single facility and for each separate chamber in Table 8. PMS data from the following two sample periods were selected for comparison with model output:

- a. December 1975
- b. Four-month average for the months of October 1975 and January, April, and July 1976

The above particular four months were chosen to provide a means of considering the slight effects of seasonal traffic variations. As explained in Part III, the model input data used in these verification tests were derived from both October and December 1975 PMS data (see Appendix B).

53. All simulation runs made during model calibration were based on a time period of 30 days and as indicated in Tables 7 and 8, the results were adjusted for comparison with the 31-day month of December. The 1 Up-1 Down lock operating rule was used in the model to coincide with current Gallipolis policies during periods of high utilization.

Adjustments to Input Data During Model Calibration Runs

54. The results of each calibration run were carefully compared with the prototype data and appropriate adjustments made to the model

input data in UTILITY 1,* TOWGEN, and WATSIM in an attempt to match all statistical measures of the historical operations at Gallipolis. In general, the following significant adjustments to the input data obtained at the lock during December 1975 were made in order to calibrate the model.

UTILITY 1

55. This program generates the tow codes for use in TOWGEN and WATSIM, as explained in paragraph 30. The tow codes were slightly adjusted for R- and J-type tows only in order to permit the model to more closely reproduce for each chamber the actual mix of the three different lockage types--singles, doubles, and setovers/knockouts. Similar adjustments to UTILITY 1 input data were required to calibrate the model for use in the Winfield study and are not uncommon due to the large number of mixed tows (the occurrence of different type and size barges in a particular tow) that are not specifically considered by the program logic. Thus, the size distribution of tows pushing R and J barges had to be adjusted to better represent the number of mixed tows. This brought the computed ratios of lockage types occurring in each chamber into closer agreement with the observed ratios.

TOWGEN

56. No changes to the basic TOWGEN input data derived from PMS were made during the model calibration efforts. Actual December 1975 average barge loadings for each barge type were used. The percent of each commodity tonnage transported by each barge type was directly input as obtained from the prototype data. The directional movements of the six commodity types were also input in exactly the same tonnage quantities reported for December 1975. The dedicated equipment percentages were adjusted for the R- and J-type barges only. All other barge types were assumed to be 100 percent dedicated. This was done to reproduce the correct ratio of empty barges.

---

* UTILITY 1 is designed to accept as input tow characteristic frequency tables and produce as output a tow code deck or file for use in TOWGEN and WATSIM.

WATSIM

57. The auxiliary chamber penalty times for selected lockage types were varied in several runs so that the use of the two chambers by various size tows could be more closely reproduced. A relatively large penalty time was placed on double-type lockages in the auxiliary chamber because the prototype data indicated that only a very few actually occurred in this chamber. A small penalty was placed on singles because of the reported low utilization of the auxiliary chamber. No penalties were imposed on the use of the main chamber. Actual lockage component times, in frequency distribution formats, were used without modification in all model calibration runs.

Effects of Light Boat Traffic

58. The TOWGEN/WATSIM model is designed to simulate commercial tow traffic on waterways and through locks, but does not consider the movement of light boats such as passenger craft, recreational vessels, and towboats without barges. An analysis of PMS data indicates that small craft traffic through the Gallipolis Locks is relatively light. For example, utilization of the locks by light boats was determined to be 0.6 percent during December 1975, and almost all of the traffic was processed by the auxiliary chamber. The percent of utilization of the auxiliary chamber was therefore reduced by this small amount, as indicated in Tables 7 and 8, for comparing the simulated utilization with a corresponding level of prototype utilization.

59. A more extensive analysis of light boat traffic at Gallipolis is presented in Table 9. As shown, monthly light boat traffic throughout the period October 1975 through September 1976 accounted for an average of only about 2.1 percent of the available time. Most of the time spent locking light boats in such small numbers would have been during slack periods or in conjunction with tow lockage activities. Light boats should therefore be able to continue locking through the auxiliary chamber without creating additional undue delays for commercial tows. Based on this analysis, the Gallipolis Locks capacity

levels determined by the simulation model were not reduced to allow for time spent in locking small boats.

Summary of Calibration Results

60. Tables 7 and 8 indicate that the final calibration run results and the corresponding prototype data compare very closely with each other in almost every case. The total number of tows passing through the lockage facility during the sampling period is reproduced within 2 percent by the model. The tonnage locked through is reproduced within 1.6 percent of the actual December 1975 total tonnage and within 6.5 percent of the four-month average, with its inherent seasonal variations. The ratio of the three lockage types analyzed and the ratios of empty to loaded barges also compare favorably in both of the cases shown in Table 7.

61. Table 8 is a comparison of simulation model results and December prototype data by chamber. The model automatically assigns each approaching tow to one of the two chambers by considering the expected time for completion of each lockage, accounting for the vessels in queue and chamber penalty times, if any, as primary criteria for chamber selection. Since the model internally controls the assignment of tows to the two chambers, the differences between the model's output and the corresponding December data are not considered to be too great. All comparative statistics are within 9 percent of each other, except the percentage of singles in the auxiliary chamber, which deviates from the actual by about 15 percent. This should not adversely affect lock capacity determinations because only a small percentage of the tows locking through Gallipolis are included in this category. All comparative statistics for the main chamber, the most important by far of the two chambers, match each other almost exactly.

Simulated Versus Actual Average Delay Times

62. One noteworthy finding made during the calibration efforts

involved the large difference between the average delay time reported by the model and the actual average delay time for December 1975. A number of additional calibration runs were made in an attempt to increase the simulated delay time to 147 min--the average delay as computed by PMS for December 1975--without significantly altering the other statistics. This, however, proved to be a frustrating exercise since any improvement in the average delay time reported by the model always resulted in undesirable changes to other key parameters such as lockage type ratios, percent utilization for one or both chambers, or tonnage levels.

63. An analysis of the PMS data over the period October 1975 through September 1976 revealed that a change in the policy for recording arrival times had occurred after February 1976. During the period October 1975 through February 1976, all tows had a recorded delay even if the approach was a fly type, but a fly approach indicates that no other tows are awaiting lockage and therefore no delays should have occurred. After February 1976, only 73 percent of all tows passing were delayed with a corresponding reduction in average delay times. The simulation model indicated that for all tows passing, 68 percent were actually delayed and the average delay for all tows was 110 min. This compares favorably with those values when the arrival times were recorded properly after February 1976.

PART V: CAPACITY DETERMINATIONS THROUGH SIMULATION MODELING

General Method for Determining Capacity

64. Two primary approaches were used to analyze the capacity of the Gallipolis lockage facilities: increases in delay time and lock utilization as functions of increased commodity tonnages. Both methods should yield similar results since the delays increase rapidly as lock utilization approaches 100 percent. Tow delay times reflect the economic costs to shippers and are indicative of both economic and physical capacity constraints. Lock utilization values are more indicative of the approach to physical capacity. Such studies give a good indication of the current lock's capability to handle the projected traffic levels. For each alternative lock operating policy and for required structural improvements, if any, the analysis involved plotting the values obtained from model output, fitting functions, and plotting curves to these data points using the least-squares method.

Lock Operating Policies Studied

65. The following operating policies, some of which are coupled with the need for minor structural improvements, were analyzed separately to compare the relative merits of each for use at the existing Gallipolis Locks.

1 Up-1 Down (1U1D)

66. Tows in queue on each side of the lock are served alternately. That is, after a tow traveling in a given direction is locked through, a tow traveling in the opposite direction is next to be locked, thereby eliminating the time required to reverse the lock. No structural improvements are required for this or the 3 Up-3 Down policy.

3 Up-3 Down (3U3D)

67. Three upbound tows are locked consecutively, followed by three downbound tows, or vice versa. If the queue in the pool from which tows

are being locked empties prior to reaching the maximum of three vessels, tows from the other pool are then selected. For this policy, it is assumed that the last two tows in sequence will approach the lock and, therefore, their entry will be the turnback (or short) entry type. However, the lock does have to be reversed without a tow in it each time two tows traveling in the same direction are locked sequentially.

First In-First Out
(FIFO) Unrestricted

68. This simply means that the tows are serviced in the order of their arrival and that no restriction is placed on their barge configuration (tow makeup) or size as they approach the lock; i.e., no remake or reconfiguration of the barges is required until after the lockage process begins.

FIFO Ready-to-Serve

69. This operating policy prohibits the break and recoupling of the large multicut size tows within or in the vicinity of a lock chamber. Each separate cut of a large tow is assumed to lock immediately following one another and each is independently powered. Knockout and setover type lockages are allowed to continue locking in the unrestricted manner, i.e., reconfiguring in the lock chamber, as necessary, to be served. This operating policy would require several switchboats permanently stationed at the lock to assist in the locking operations or a "help-the-other-tow" policy where power units from tows waiting in queue would assist locking tows.

Switchboat operations
and/or lock wall extensions

70. In this operating condition all tows would be allowed to enter the lock in their river configuration. Multicut lockage tows would break apart from their unpowered cuts upon entering the lock chamber and, following lockage, the unpowered cuts would be pushed by a switchboat to a mooring area to await the recoupling of any subsequent unpowered cuts, and finally, the powered cut. Knockout and setover size tows would continue to break and reconfigure for lockage inside the chamber, but following the chambering process, they would be required to move, either

under their own power or with the help of a switchboat, to a mooring area before reconfiguring for river travel. The following alternative means of increasing the capacity of the lock through the use of switchboats and associated structural improvements were analyzed for the 1U1D, 4 Up-4 Down (4U4D), and FIFO Unrestricted operating policies:

a. Switchboat operations in the upper pool only

b. Switchboat operations in both the upper and lower pools

c. Switchboat operations in the upper pool and an extended center guard wall in the lower pool

d. Switchboat operations in the upper pool and an extended landward guide wall in the lower pool

Reduction and Analysis of WATSIM Output

71. At the end of a 47,521 min simulation time, the WATSIM program prints out cumulative delays, commodity tonnage, the number of tows processed and the other data shown in Figure 1. The 47,521 min actually represent one 30-day month of simulated locking operations since the tows serviced during a specified 4,321 min warm-up time are not included in the output. Since the model starts with zero tows to process, a warm-up period is required to allow ample time for steady state conditions to be established. For each selected tonnage year up until infinite queuing occurs, the pertinent data to be plotted were obtained from Table 13 (similar to Figure 1 in this report) of the respective WATSIM printouts.

Projected Tonnage Levels

72. The historical and projected tonnage levels used in the simulation runs are shown in Tables 10 and 11. Table 10 presents the projected tonnages for future years on a monthly basis and reveals that the traffic is reasonably uniform throughout the year, with slightly higher tonnages during March and May, and with lower tonnages in July. Table 11 partitions estimated tonnage movements by commodity group and

direction of travel for input to the TOWGEN model. Tonnage projections through the year 1985 were furnished by the Huntington District; however, it was necessary to extend the projections through the year 1992 to make simulation model runs of infinite queuing conditions for the improved operating policies tested. All tonnage projections beyond the year 1981 were based simply on straight-line extensions of the 1976-1981 trends. Projections through 1981 were based on a detailed economic and physical analysis of predicted resource demands. There could be concern by some regarding the validity of the projected tonnages beyond 1981; however, because of the relatively high expected utilization of the locks after 1981, only small differences would be recognized in the WATSIM-computed capacity, regardless of the exact tonnage levels put into the model. In addition, the inherent limitations involving the increased use of the auxiliary chamber (e.g., approach channel blockage caused by operations in the main chamber) would cause tow delays to be even greater than those indicated for future years by the model output.

73. To generate the proper number of the various types and sizes of tows for use in WATSIM, an annual tonnage level for each commodity was input to each TOWGEN run, together with a "divisor" of 10.75 for converting the annual tonnage levels shown in Table 11 to monthly maximums. Computation of this divisor was based on the average maximum tonnage that passed through the locks during a single month. The output subsequently obtained from the WATSIM runs therefore represents the most severe traffic conditions to be expected at the lock during a given month. As mentioned above, the model assumes that the auxiliary chamber would continue to be used more and more as traffic increases. However, the physical design of this two-chamber lock is such that approaching/exiting tows and unpowered cuts of double lockage on the guide walls of the main chamber often interfere with operations in the auxiliary chamber. The magnitude of this interference was analyzed and its effects are discussed later in the report.

74. The predicted increasing tonnage levels were put into the simulation model until "infinite queuing" occurred. This does not mean that the queue length was actually infinite but that a preset number of

waiting tows had been reached. The queue limits set were 50 tows for the 1U1D, 3U3D, and FIFO Ready-to-Serve policies and 30 tows for the FIFO Unrestricted. The lock reached very nearly maximum utilization for the 30-tow queue during the FIFO Unrestricted runs, and thus going to a longer queue length was not necessary. These queue lengths, though arbitrarily set, were chosen for two reasons. First, either 30 or 50 tows waiting to be serviced on each side of the lock is considered an impossible situation from a practical standpoint, especially since the average interarrival time (time between tows arriving at the lock) at that traffic level is much less than the average service time. Secondly, as in the prototype, the queues are not static, but build and diminish. With a more reasonable preset queue limit (say 15 tows), a slight increase in the number of tows in queue might cause premature termination of a simulation run; i.e., infinite queuing would occur due to an unusual series of tow arrivals before the desired high levels of lock utilization are reached. To avoid such occurrences and to allow very high lock utilization values and tow delays, two large numbers--30 or 50, depending on the simulated operating policy--were chosen for these runs.

Interpretation and Use of the Capacity Curves

75. For each alternative lock operating policy the analysis involved plotting the experimentally determined values, fitting functions, and plotting curves to the data points using the least-squares method. Using the output from the simulation model, monthly delay versus monthly tonnage plots were made for the alternative operating policies tested. The limited data obtained for the 3U3D operating procedure were plotted on the same sheet as the 1U1D policy. These plots (see curves in PARTS VI and VII) show the expected rate of increase of monthly delays as tonnages moving through Gallipolis Locks and Dam grow in future years.

76. The delay versus tonnage curves become asymptotic as tonnage levels increase. That is, at some point on the delay versus tonnage

curve, a slight increase in tonnage will cause an extremely large increase in total delay. When this occurs, an unstable condition in the relationship between delay and tonnage develops, which makes it difficult to determine a specific delay time associated with a particular tonnage.

77. The region where the delay versus tonnage level approaches an asymptotic value of tonnage defines the physical limitation of tonnage or capacity that can be serviced under given operating conditions (service times, lock operating policy, fleet characteristics, and commodity mix at given tonnage levels). Practical tonnage capacity levels would fall below this region primarily due to four reasons:

a. At such high lock utilization levels, the total delay of tows is very sensitive to the specific tow arrival pattern.

b. Small changes in particular queuing characteristics can cause dramatic increases in the delay costs incurred by the towing industry.

c. No allowance is made in the simulation procedure for maintenance and accident downtime, nor for utilization of the locks by recreational craft and workboats.

d. The auxiliary chamber at the existing facility can never be fully utilized because of the interference caused by tows using the main chamber.

78. A study of the increase in commodity tonnage and delay time as a function of lock utilization is another means of analyzing the capacity of a lock. Tonnage versus utilization is linear in most cases and once a specific value of utilization is chosen to represent the capacity level, a specific level of tonnage associated with that utilization can readily be obtained for use in an economic evaluation of both structural and nonstructural alternative lock improvements. The third type of curve, delay versus utilization, is provided so that a corresponding total delay time to be expected for any selected utilization level can also be determined.

79. With the tonnage versus utilization and delay versus utilization plots, some of the other variables of lock operation can be considered by adjusting utilization and obtaining a revised tonnage capacity

level. This becomes necessary because the simulation model does not account for all factors involved in the capacity of a lockage facility. For example, as mentioned above, the simulation model used for this study considers only the tows with one or more barges. It has no direct means of introducing workboats, towboats without barges, pleasure craft, or other relatively small boats into the simulation process. The utilization curves provide a means of subtracting the percentage of lock utilization attributed to these other users. The Gallipolis Locks, however, service a relatively small volume of light boat traffic, which as explained earlier, does not significantly delay the passage of commercial tows at this time, but nevertheless accounts for a small percentage of lock utilization. Other factors such as downtime due to mechanical failures, maintenance, and accidents can also be easily considered by using this type of capacity definition.

PART VI: CAPACITY OF THE EXISTING GALLIPOLIS LOCKS

Summary of the WATSIM Model Output

80. The data used in determining the capacity of the Gallipolis Locks were obtained from the final Table 13 (see Figure 1) of each WATSIM printout. These data corresponded to a simulated period of one month. The delay times in minutes were converted to hours so that the reader could better relate to the extremely high total delays indicated for future years. Table 12 shows the operating policies and years for which simulation model runs were made. Only three test runs of the 3U3D operating policy were made since results in the out years (1983, 1984, and 1986) indicated greater delays for this policy than for the 1U1D rule. Thus there would be no advantage in using this policy for the existing locks. The data shown in Table 12 were plotted for each operating policy as follows:

- a. Monthly delay versus monthly tonnage
- b. Monthly tonnage versus percent utilization
- c. Monthly delay versus percent utilization

Curves were fitted using the least-squares method and functional relationships developed as shown on each plot.

1 Up-1 Down and 3 Up-3 Down Operating Policies

81. The capacity curves developed for these two similar operating policies are shown in Figures 3-5. In Figure 3, the maximum monthly tonnage would not reach six million tons for this operating policy before experiencing exorbitant delays. Figure 4 indicates that a lock utilization of 96.5 percent would be necessary to pass six million tons. Such a utilization level is physically impossible at this lock facility primarily because of the problems involved in making full utilization of the auxiliary chamber and the additional requirements for lockage services that are not considered by the model. Delays to be expected at various levels of lock utilization can be obtained from Figure 5.

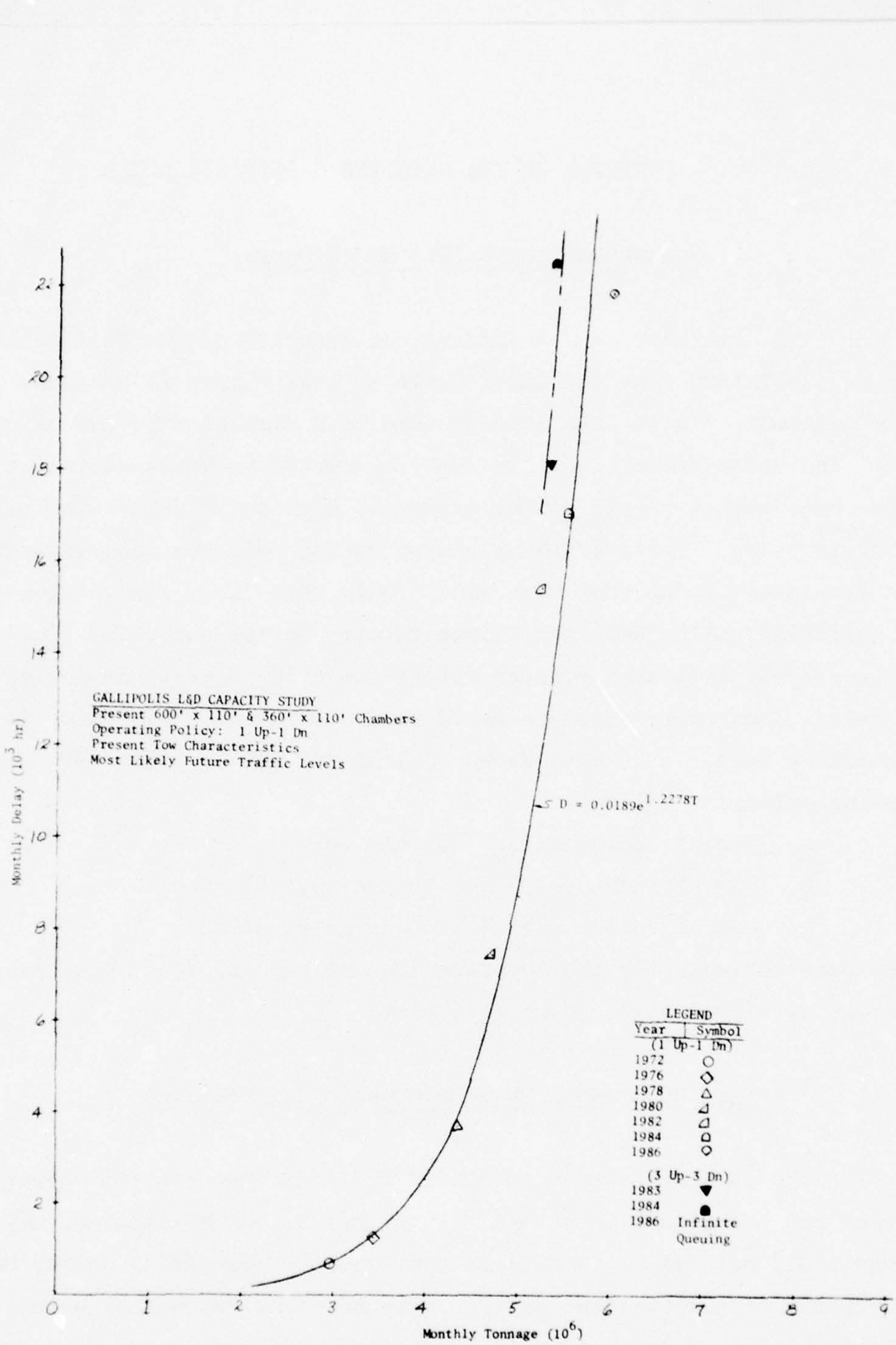


Figure 3. Monthly delay versus monthly tonnage for the 1U1D and 3U3D operating policies with present conditions at the locks

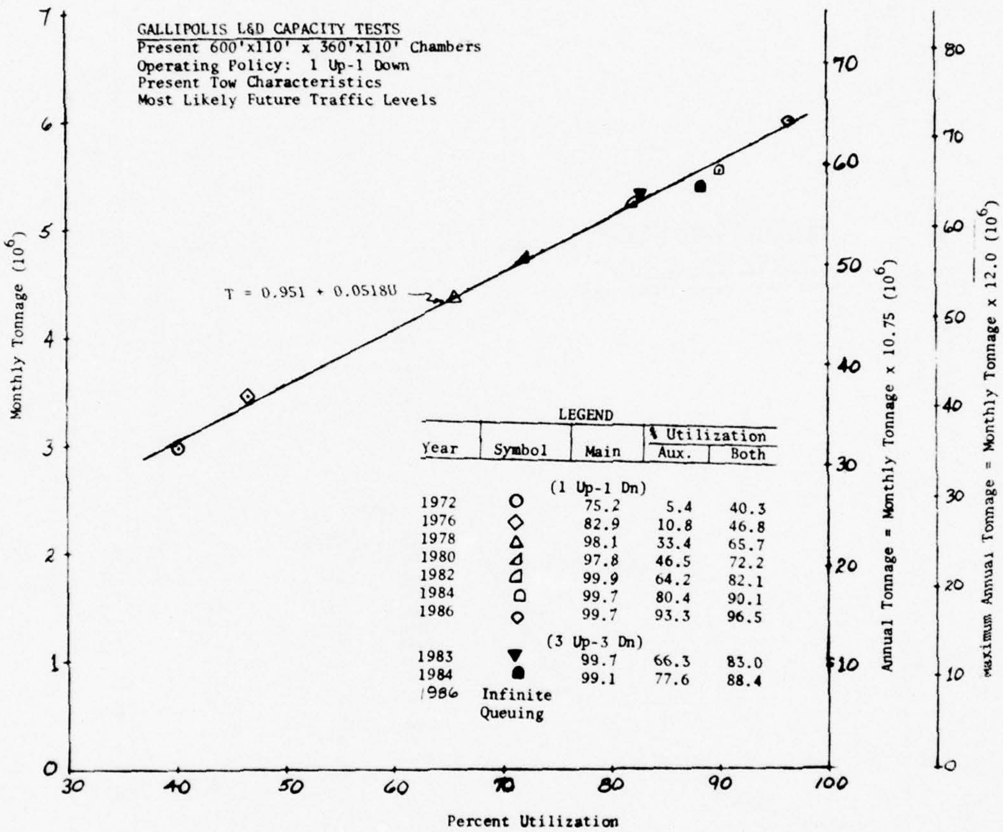


Figure 4. Monthly tonnage, annual tonnage, and maximum annual tonnage versus lock utilization for the 1U1D and 3U3D operating policies with present conditions at the locks

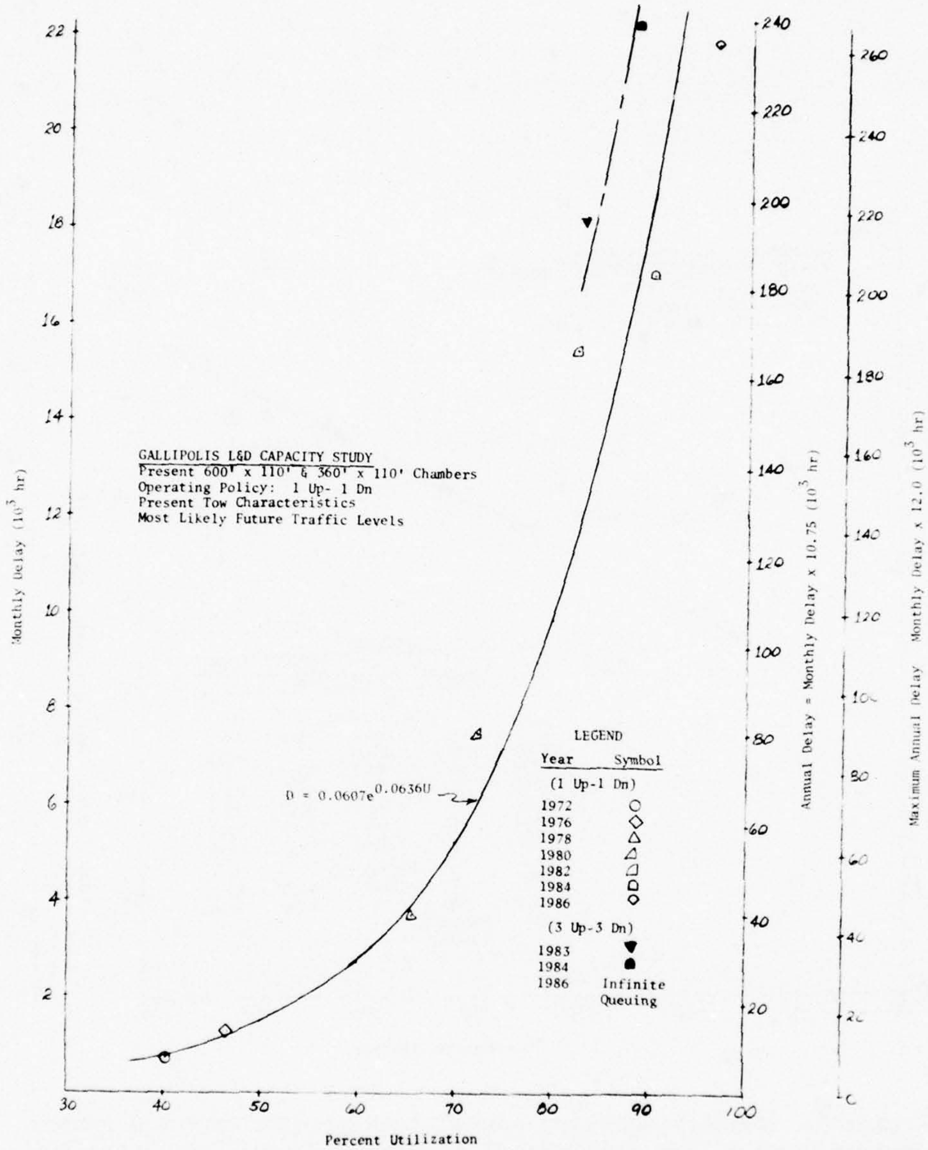


Figure 5. Monthly delay, annual delay, and maximum annual delay versus lock utilization for the 1U1D and 3U3D operating policies with present conditions at the locks

82. Only two points were plotted for the 3U3D policy because of the greater delays and longer queues indicated by the three model runs made. During the third run of the 3U3D policy, infinite queuing occurred in 1986, but did not occur until 1988 for the 1U1D policy. As a result, further model runs were not made to fill in the bottom of the curve for the 3U3D policy.

FIFO Unrestricted Operating Policy

83. The results of the WATSIM runs are plotted for the FIFO Unrestricted operating policy in Figures 6-8. In comparing the monthly delay versus monthly tonnage curve for 1U1D with the corresponding curve for FIFO Unrestricted, there appears to be no significant difference in the delays and tonnages of the two. Neither operating policy would achieve the six million tons per month that the curve appears to be approaching because of the necessary high utilization levels required in both chambers. As mentioned earlier, use of the auxiliary chamber is severely limited by traffic in the main chamber.

Theoretical Maximum Tonnage Capacity of Existing Locks

84. The theoretical maximum tonnage capacity of a lock is the maximum tonnage that could be passed through it, assuming 100 percent utilization. It is referred to as the "theoretical" maximum because a 100 percent level of utilization obviously could never be attained at any lock. The computations were made for reference only, as a point of interest, to show the uppermost bounds of tonnage throughput at the existing Gallipolis Locks. The maximum tonnages for each operating policy and year may be compared with one another as a supplemental means of determining the relative increases in lock capacity, if any, to be expected from the various alternative operating policies.

85. Maximum capacity computations associated with the 1U1D, 3U3D, and FIFO Unrestricted operating policies are given in Tables 13-15, respectively. The desired values, maximum tons per month and

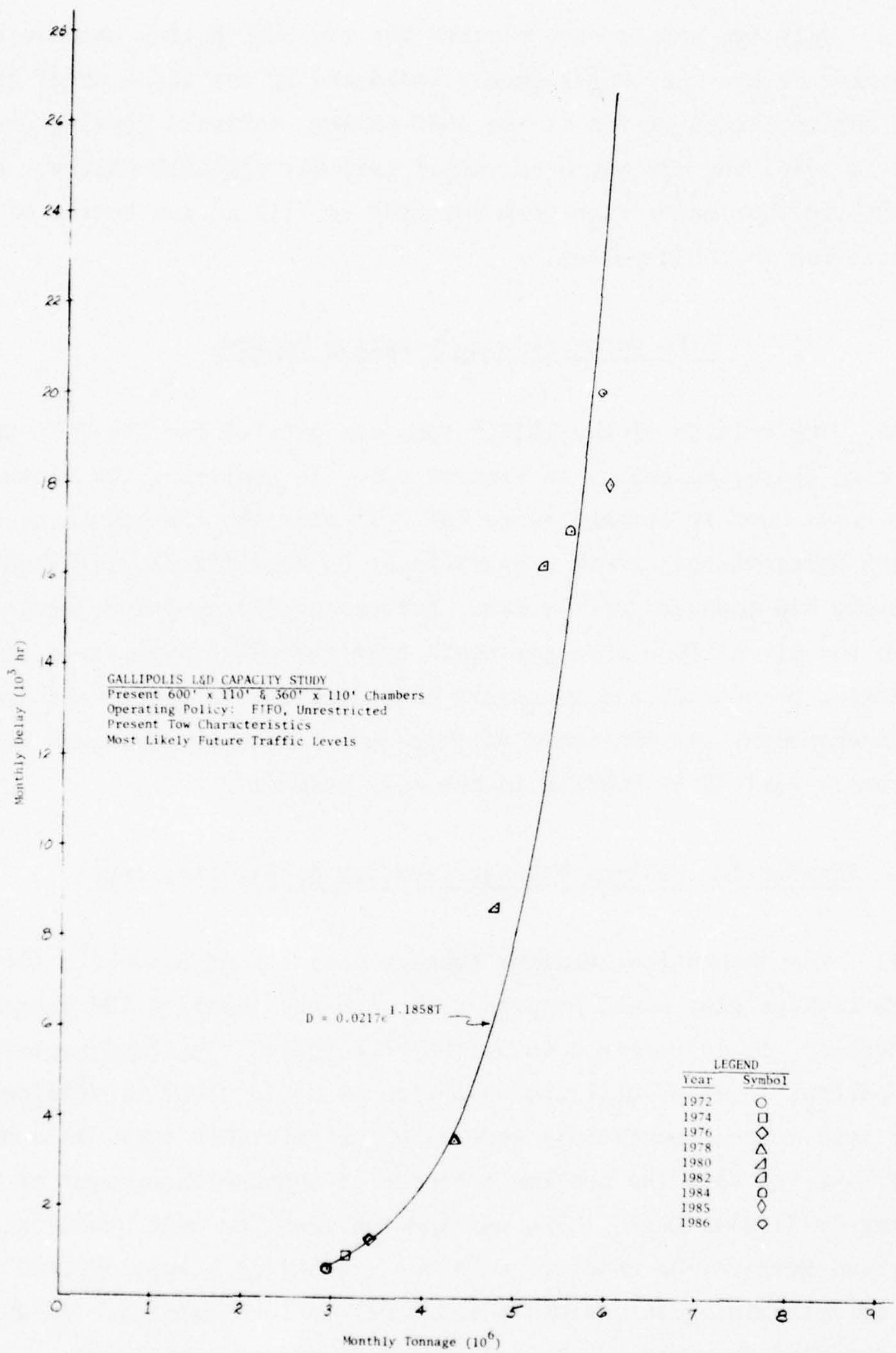


Figure 6. Monthly delay versus monthly tonnage for the FIFO Unrestricted operating policy with present conditions at the locks

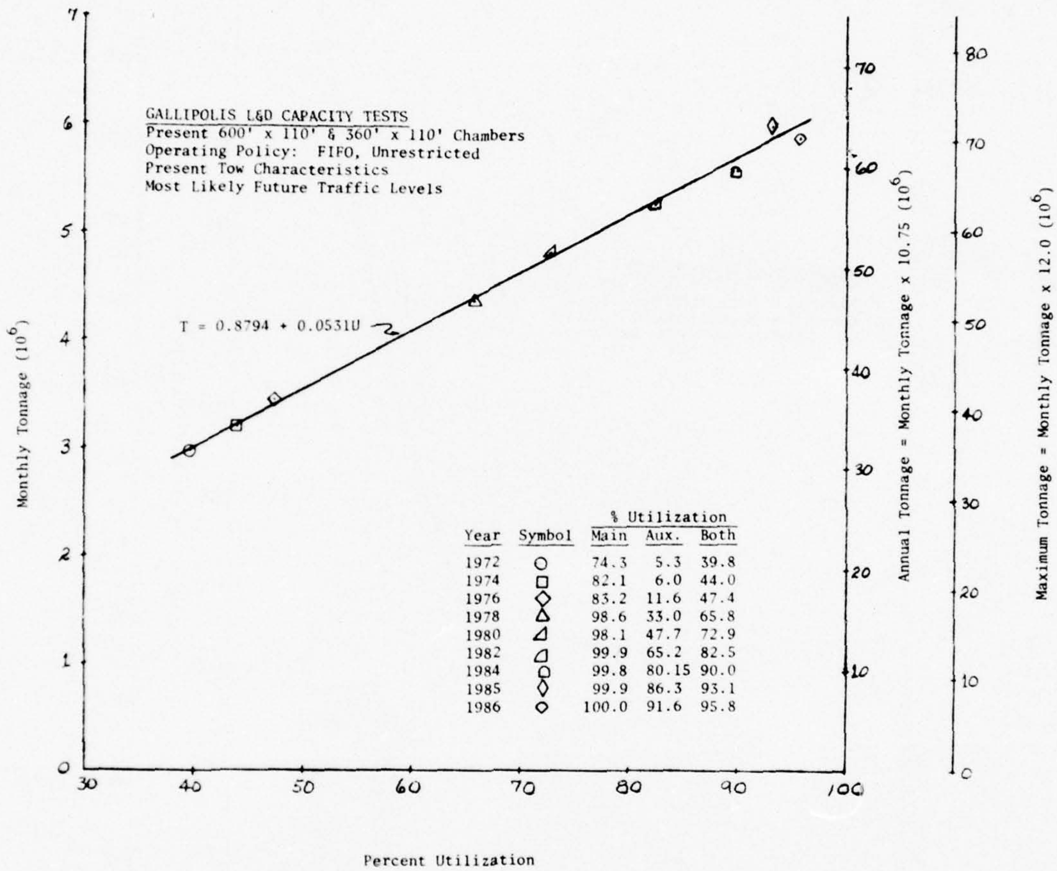


Figure 7. Monthly tonnage, annual tonnage, and maximum annual tonnage versus lock utilization for the FIFO Unrestricted operating policy with present conditions at the locks

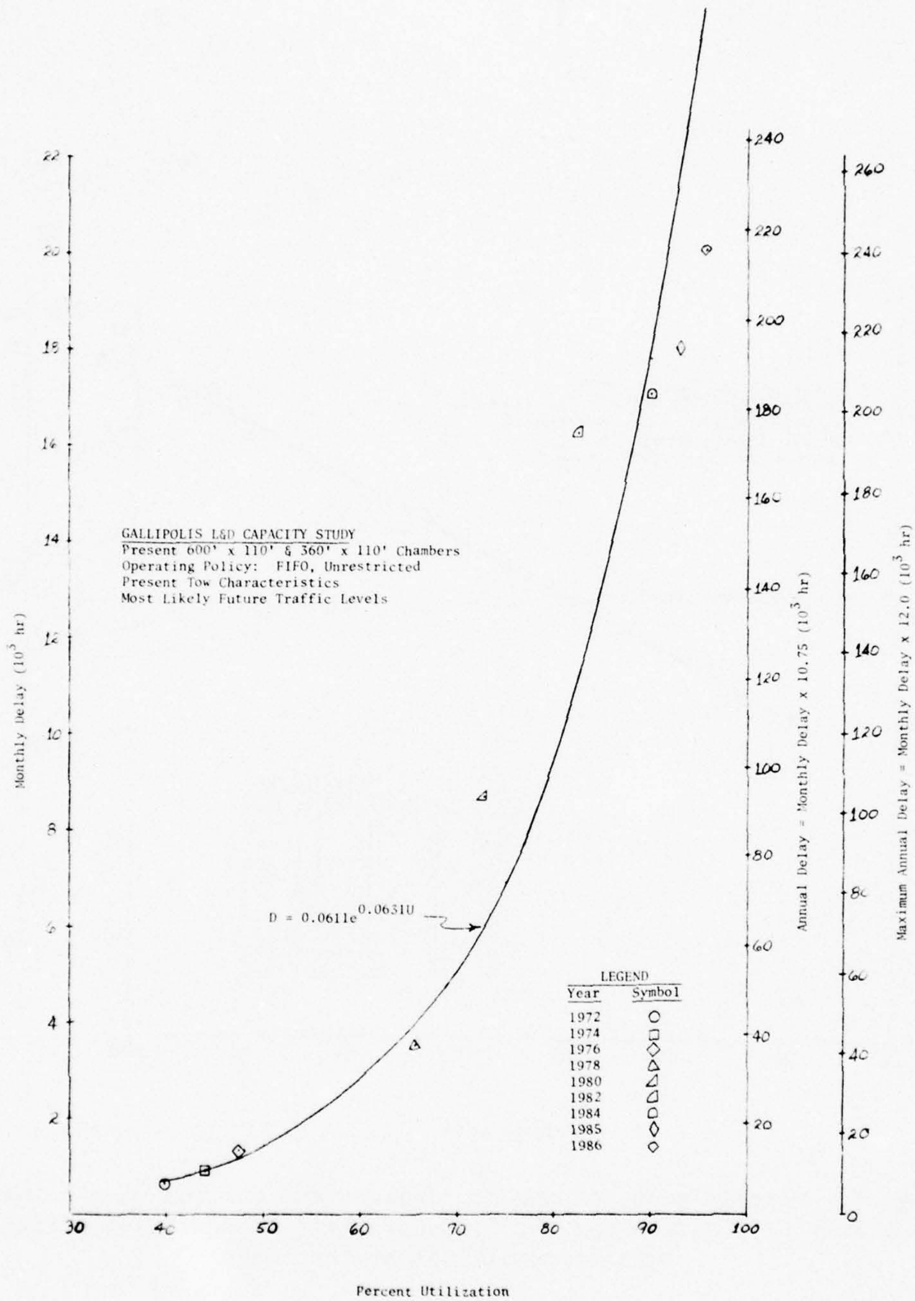


Figure 8. Monthly delay, annual delay, and maximum annual delay versus lock utilization for the FIFO Unrestricted operating policy with present conditions at the locks

maximum tons per year, are derived separately for each chamber and for several selected years in the following steps.

Tows per lockage

86. The total number of each lockage type--singles, doubles, setovers, etc.--is given by chamber in the WATSIM output (see Figure 1). For all lockage types except multitow lockages, one tow is processed by WATSIM for each occurrence of a lockage type. Thus the sum of the number of occurrences of a lockage type, regardless of lockage type (with the exception of the negligible number of multitow lockage types), is the same as the number of tows. To determine the actual total number of lockages (chamber filling or emptying), single and setover tows take only one lockage, doubles require two, and triples and over are considered to be three, even though some tows would require more than three cuts in the auxiliary chamber. Thus, the number of tows per lockage computed for the auxiliary chamber is probably a little high for the out years when more of the large tows would choose multicut lockage in the auxiliary chamber rather than wait unusually long periods to use the main chamber.

Average time per lockage

87. The total processing time by chamber is divided by the number of lockages that occurred.

Maximum lockages per month

88. This value is derived simply by dividing the total number of minutes in a month (43,200) by the average time required for each lockage.

Tons per barge

89. Barge types of the same mix are assumed to use each chamber; therefore the tons per barge is the same regardless of the chamber. Total tons processed by both chambers during a simulated month are divided by the number of barges locked.

Barges per tow

90. The number of barges serviced by each chamber is divided by the number of tows.

Barges per lockage

91. The tows per lockage are multiplied by the barges per tow to obtain the desired values.

Tons per lockage

92. The tons per barge is multiplied by the barges per lockage.

Theoretical maximum tons per month

93. This highest possible capacity of the lock is determined by multiplying the maximum lockages per month by the tons per lockage. The value thus obtained represents a maximum, but impractical, monthly tonnage level. Such tonnages through either chamber would not be possible because of the loss of commercial traffic locking time due to downtime for maintenance, accidents, adverse river and weather conditions, and lockage of vessels not carrying commercial cargo. In addition, full operation of the main chamber interferes with operations in the auxiliary chamber. Tows using the auxiliary chamber would also interfere to some degree with operation of the main chamber.

Maximum tons per year

94. The maximum tons per month was multiplied by 10.75 to obtain the maximum tons per year. A multiplier of 10.75 rather than 12.0 was used because 10.75 was the divisor used for each commodity tonnage in TOWGEN to convert from annual levels to monthly maximums. Thus the heaviest traffic conditions to be expected during any given month of each test year were put into the model to simulate maximum lock utilization and the accompanying larger delays.

Analysis of Interference to Operations in the Auxiliary Chamber

95. The auxiliary lock at Gallipolis cannot be used by tows at certain times when the main chamber is in use. The present entrance conditions are such that the entire channel must be occupied by the tows entering and exiting from the main chamber. In addition, interference to operations in the auxiliary chamber is caused by portions of tows secured on the main chamber guide walls during double lockages. Every effort is made to prevent operations in the smaller auxiliary

chamber from interfering with main chamber operations.

96. The adverse effects of main chamber operations on the auxiliary chamber capacity was analyzed using the PMS data for the month of December 1975. Single, setover, knockout, jackknife, and multivessel lockages in the main chamber were assumed to have blocked entrance to and exit from the auxiliary chamber as they approached, entered into, and exited from the lock. The break and recoupling times of setover, knockouts, and jackknifes are an integral part of the entry and exit times, respectively, and were therefore included in the channel blockage times. Double lockages blocked the entranceway during these times and also when separate cuts were moored to the guide walls of the main chamber. The results of the data analysis are shown in Table 16. The significant point to note is that the upper approach and lower approach were blocked by operations in the main chamber 56.1 percent and 55.0 percent of the processing time, respectively. The assumption was made that no tows were in the area of the lock during times when the main chamber was not in operation. Had there been any, they would have most likely used the main chamber in lieu of the auxiliary chamber. Accordingly, the total processing time of the main chamber rather than the total available time was used to compute the percent of time the approach channel could not be used by tows desiring to enter the auxiliary chamber. The December 1975 data thus indicated that unless the tows could be scheduled for lockage so as to circumvent periods of channel blockage, only about 45 percent utilization of the auxiliary chamber would be attainable during periods when the main chamber is heavily utilized and standard double lockages were being performed frequently.

Hazardous Approach and Exit Conditions at the Auxiliary Chamber

97. The hazardous approach and exit conditions existing at Gallipolis Locks and Dam (schematically depicted to scale in Figures 9-13) are described in the following paragraphs.

High flow conditions

98. During high flow conditions (total gate openings greater than

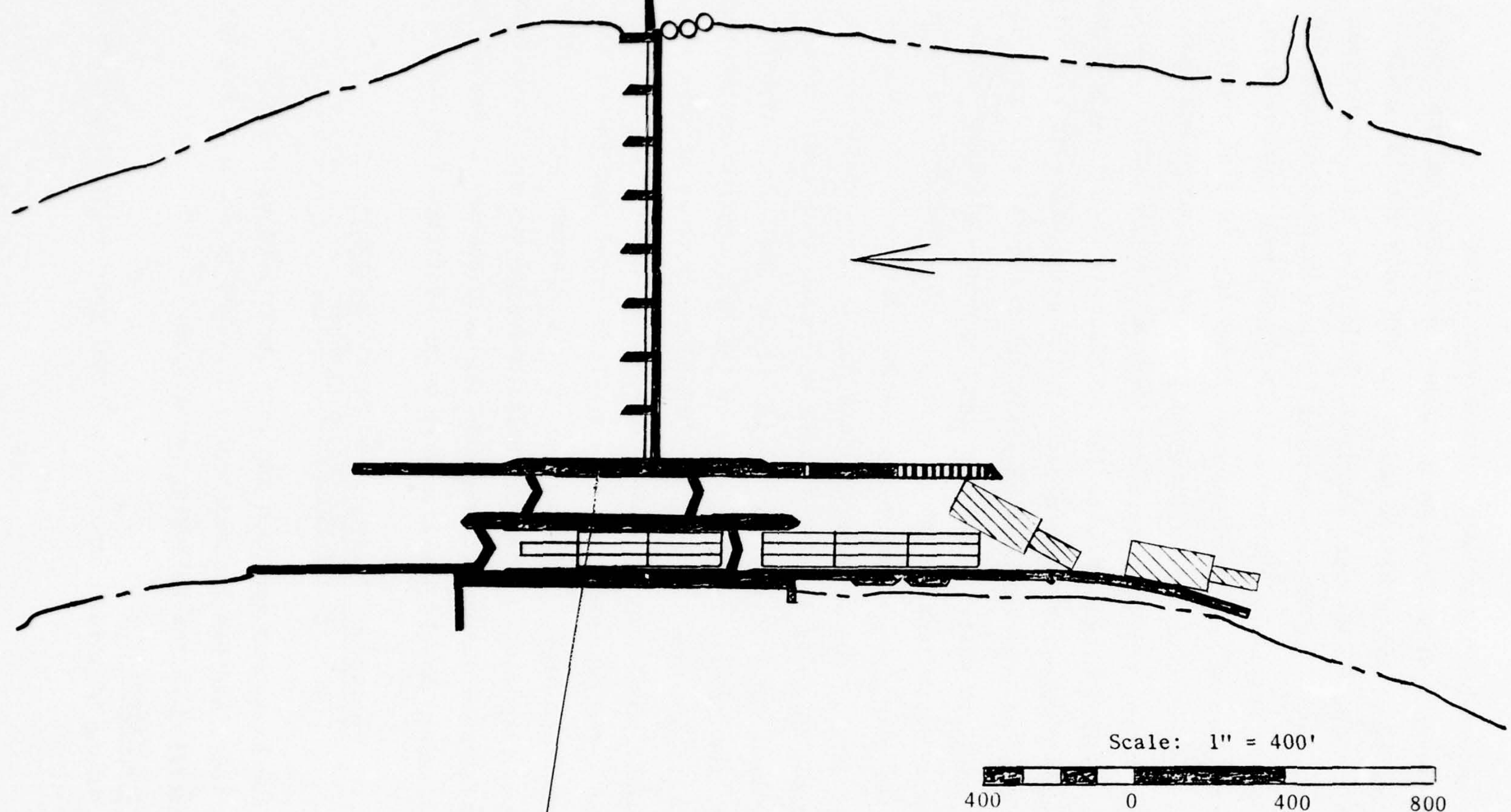


Figure 9. Unsuccessful attempt by a downbound 360- by 105-ft tow to enter the Gallipolis auxiliary chamber during a high flow period with the channel partially blocked by an unpowered cut of a double lockage moored to a guide wall

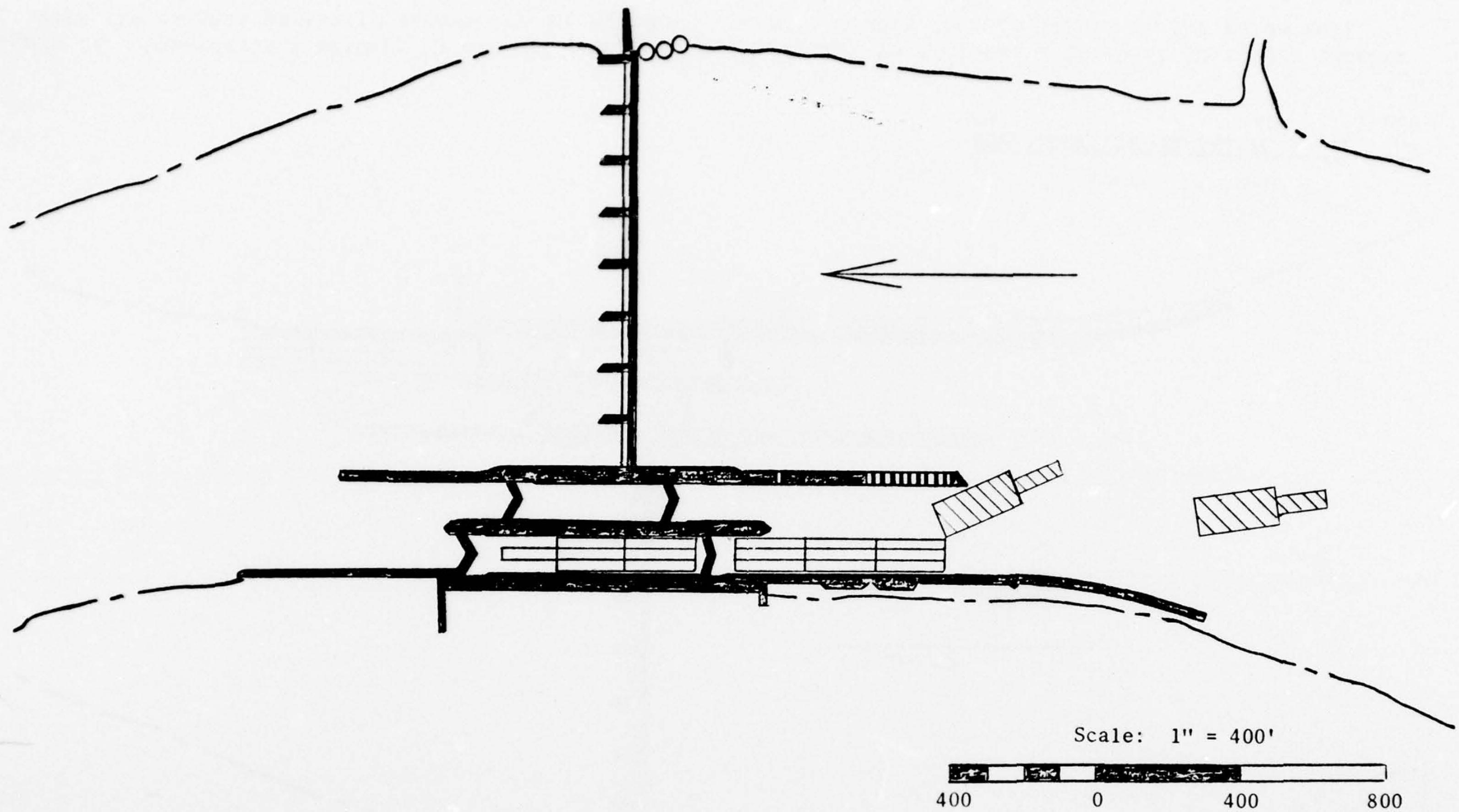


Figure 10. Unsuccessful attempt by a downbound 360- by 105-ft tow to enter the Gallipolis auxiliary chamber during a low flow period with the channel partially blocked by an unpowered cut of a double lockage moored to the guide wall

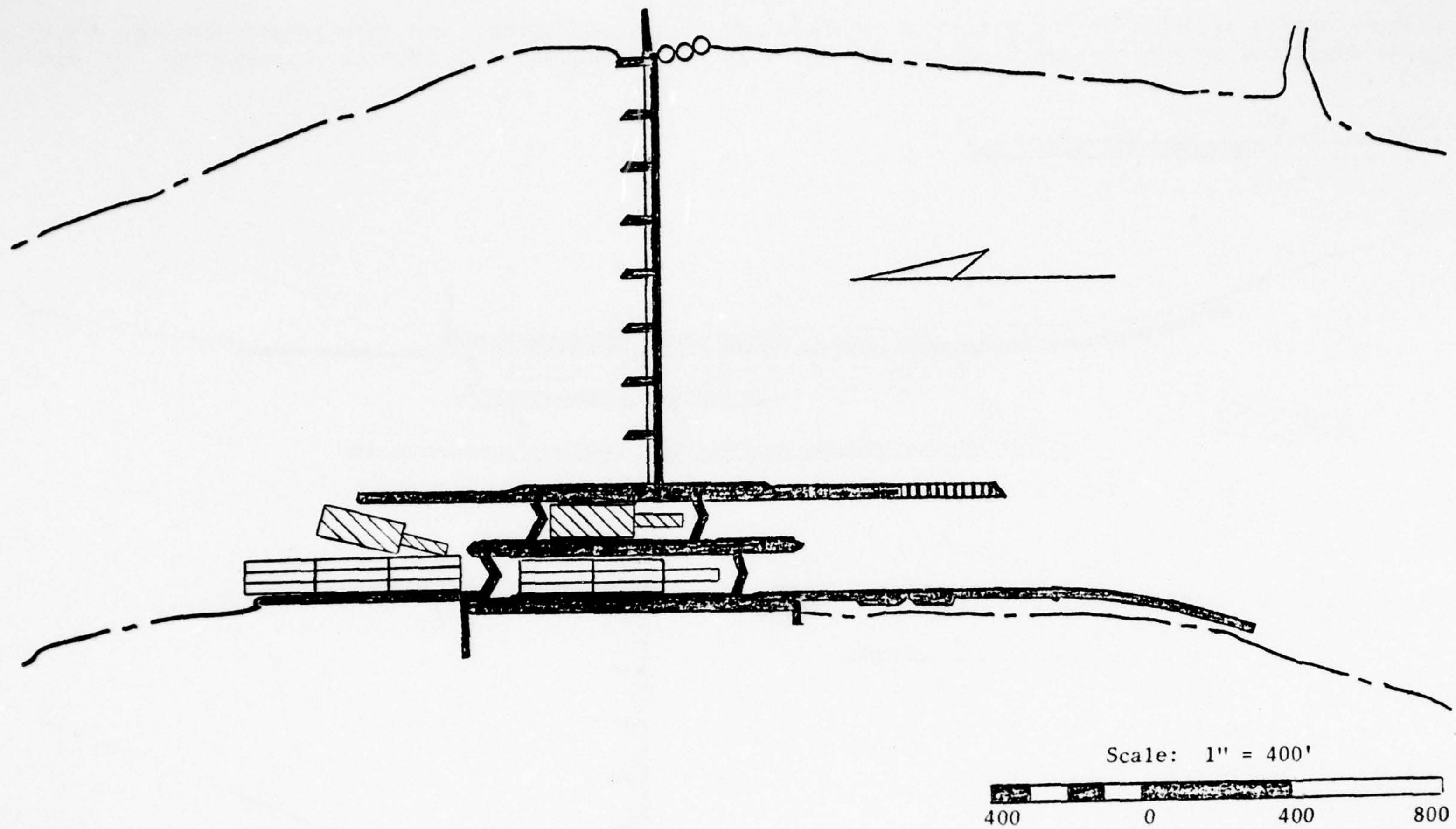


Figure 11. Unsuccessful attempt by a downbound 360- by 105-ft tow to exit the Gallipolis auxiliary chamber with the channel partially blocked by an unpowered cut of a double lockage moored to the guide wall

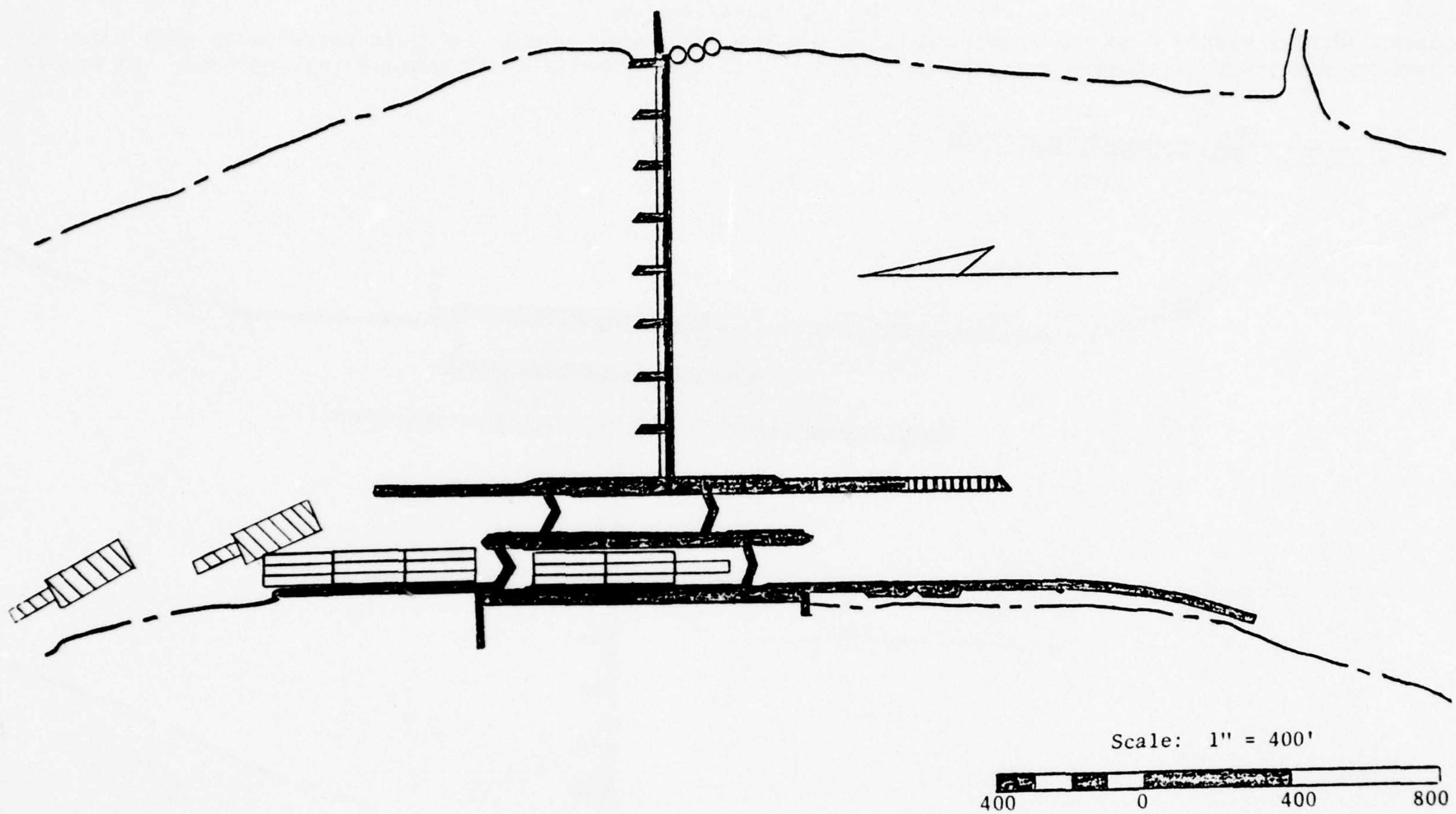


Figure 12. Unsuccessful attempt by an upbound 360- by 105-ft tow to enter the Gallipolis auxiliary chamber with the channel partially blocked by an unpowered cut of a double lockage moored to the guide wall

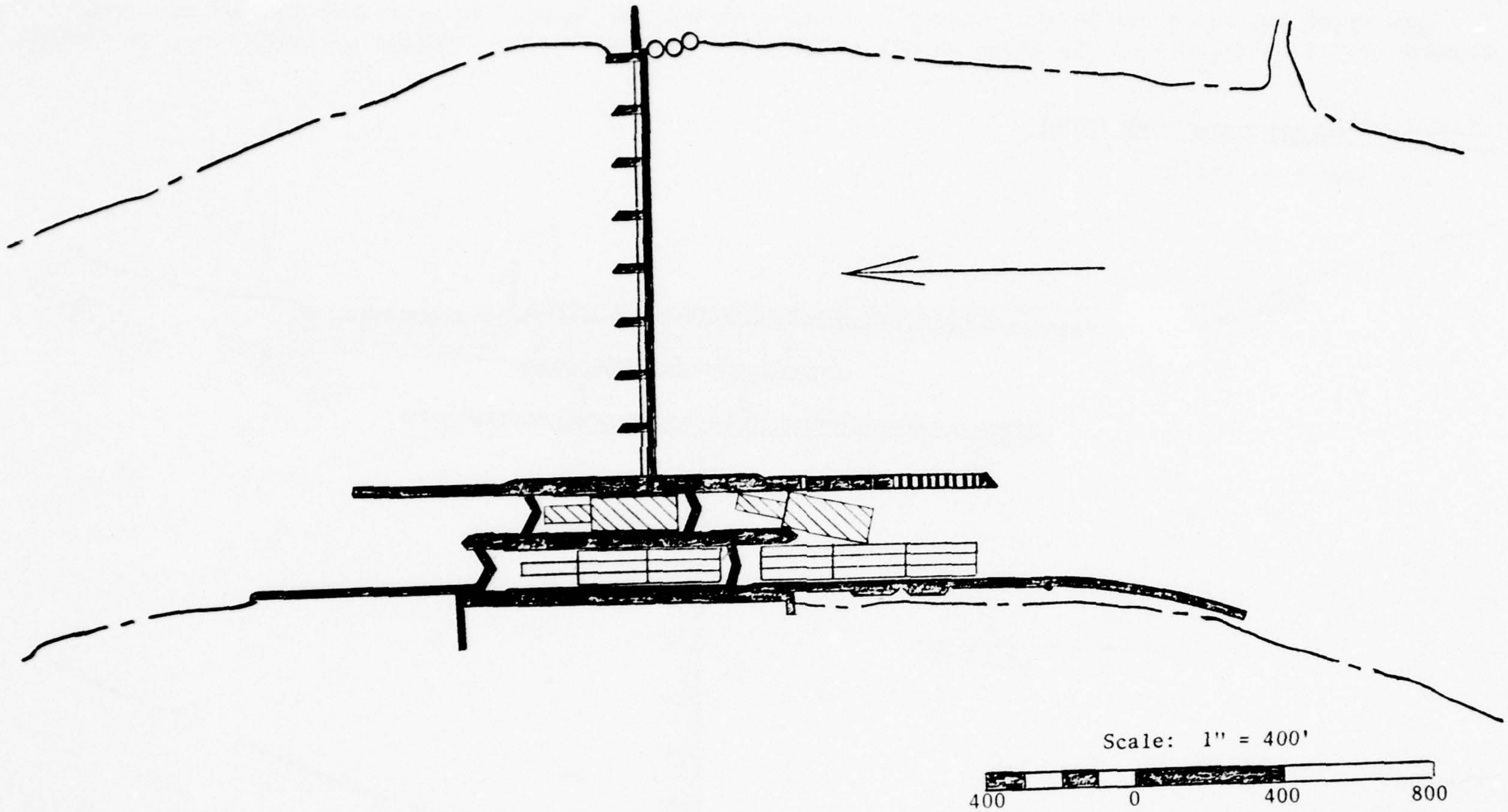


Figure 13. Unsuccessful attempt by an upbound 360- by 105-ft tow to exit the Gallipolis auxiliary chamber during a high flow period with the channel partially blocked by an unpowered cut of a double lockage moored to the guide wall

25 ft*), tows must work their way along the guide wall to enter the auxiliary chamber. Checkline assistance must often be used to offset the outdraft currents. As shown in Figure 9, tows would be unable to maneuver around an unpowered cut on the guide wall without the risk of being swept out past the end of the upper guard wall.

Low flow conditions

99. During low flow periods, reduced outdraft currents still tend to force the bow of downbound tows out past the end of the upper guard wall. Tows must therefore continue to skew their approach to the auxiliary chamber. Even as the bow reaches slack water, currents continue to rotate the stern riverward toward the gates of the dam. As shown in Figure 10, attempting to maneuver into the auxiliary chamber while an unpowered cut is moored to the guide wall would be extremely hazardous.

Discharges through the dam

100. Discharges through the dam sweep around the end of the lower guard wall, giving the downstream current a sharp landward set. A downbound tow leaving either chamber must steer the bow riverward to offset the river currents that drive the entire tow toward the left bank. Figure 11 shows an exiting tow trying to maneuver to its right to offset the subject currents but experiencing great difficulty because of the moored unpowered cut on the guide wall.

Currents at the lower guard wall

101. Because of the currents whipping around the end of the lower guard wall, approaching upbound tows must assume a heading skewed to the actual alignment of the locks. As shown in Figure 12, entry into the auxiliary chamber when an unpowered cut is moored to the guide wall would be difficult and hazardous, if not impossible.

Crosscurrents

102. Conditions at Gallipolis also adversely affect the exit of upbound tows from the auxiliary chamber when an unpowered cut of a double is moored to the upper guide wall. A boat pilot must try to

* A gate opening of 25 ft corresponds to 18.7 ft on the lower gage (6.7 ft of tailwater).

steer the bow of the tow landward to minimize the adverse effects of crosscurrents created by the outdraft. Figure 13 shows that such a maneuver would be hazardous in many cases because of the narrow passageway.

Comparison of Three Alternate Operating Policies

103. The results of the capacity investigation are consolidated for three alternate operating policies in Table 17. First, the table shows the increase in cumulative lock utilization (both chambers combined) as traffic levels increase with the selected past and future years. Data on utilization were obtained from runs of the simulation model, using the pertinent tonnage shown in Table 11 as input data. The tonnage capacity limitations of the locks are shown in three different forms in Table 17. First, the theoretical maximum tonnage should be considered as the absolute uppermost bounds of lock capacity obtained only through 100 percent utilization of both chambers. Such levels of tonnage throughput are impossible to attain at Gallipolis under any conditions and are shown simply for comparative purpose. The theoretical maximum tonnages presented in this table correspond to the most distant future years for which simulation model runs could be made before infinite queuing occurred, as shown in Tables 13-15. The simulated maximum tonnage capacities of the locks were also obtained from the model runs for each alternate operating policy during the simulated years immediately before infinite queuing occurred. The simulated maximum tonnages are too high from a practical standpoint since higher utilization of the locks than possible would be necessary to attain them.

104. The adjusted practical maximum tonnage capacity is the most representative estimate of maximum tonnage capacity based on realistic utilization levels expected under actual operating conditions at the locks. As discussed earlier and verified by an analysis of PMS data as shown in Table 16, utilization of the auxiliary chamber can probably not exceed 45 percent with the present entrance conditions at Gallipolis and the high percentage of large tows requiring double lockages. A

95 percent level of utilization for the main chamber could possibly be achieved by insuring that operations in the auxiliary did not interfere in any way. This would be justified from the standpoint of the much greater capacity available in the larger main chamber and thus the desirability of not allowing its operation to be interrupted. Utilization of the main chamber by commercial tows could probably never exceed the 95 percent level because of unfavorable weather and navigation conditions, maintenance requirements, downtime for repairs, and other contingencies. With an assumed practical utilization level of 70 percent (95 percent in the main chamber and 45 percent in the auxiliary), the plots of tonnage versus utilization (Figures 4 and 7) were used to determine the monthly and annual practical maximum tonnage levels. Since maximum monthly tonnages were used as model input, the annual high and most likely tonnages were computed by multiplying the model output tonnages by 12.0 and 10.75, respectively. Since a divisor of 10.75 was input to the model along with the annual tonnage in Table 11, a multiplier of 10.75 converts the maximum monthly capacity to a most likely annual capacity. When the peak monthly tonnage is multiplied by 12 to obtain the maximum annual practical tonnage, the assumption is made that the peak tonnage will be processed each month.

105. An additional adjustment had to be made to the practical tonnage capacity obtained from the simulation model in order to relate simulated tonnage to the more accurate tonnages reported to the Waterborne Commerce Statistics Center (WCSC) by the towing industry. When this project was initiated, only the lockmaster's records for the month of December 1975 were available through the PMS for use in calibrating the WATSIM model. These records were the best available at the time the simulation program runs were made. However, the WCSC data made available later indicated that much less tonnage than reported by the lock personnel actually passed through the lock. The WCSC data is considered to be the more accurate because it is reported to WCSC by the home office of the shipper from actual shipping records. The lockmaster's records are simply estimates of cargo tonnages made by the towboat pilot. Use of the higher tonnage level reported by the lockmaster

resulted in a higher average load per barge in the simulation model. The model output therefore indicated a correspondingly higher tonnage capacity for the lock. To adjust for the discrepancy and obtain a more realistic capacity estimate, the practical monthly and annual tonnage capacities reported by the model were multiplied by a correction factor of 0.877. This factor is simply the ratio of the WCSC tonnage and the lockmaster's tonnage for the Gallipolis Locks.

PART VII: INCREASED CAPACITY OF GALLIPOLIS LOCKS FROM SWITCHBOAT OPERATIONS AND MINOR STRUCTURAL IMPROVEMENTS

General

106. With the aid of simulation modeling, a study was made of certain relatively minor structural and associated operational improvements that have the potential to increase the capacity of Gallipolis Locks to the limits of the existing chamber sizes. The following proposed improvements were analyzed using the TOWGEN/WATSIM simulation model package:

a. Switchboat operations in the upper pool only (Recoupling area must be constructed, e.g., mooring cells upstream from the locks.)

b. Switchboat operations in both the upper and lower pools (Recoupling area would also be required in the lower pool.)

c. Switchboat operations in the upper pool and an extended center guard wall in the lower pool, together with other improvements to local navigation facilities

d. Switchboat operations in the upper pool and an extended landward guide wall in the lower pool to enable the remaking of tows outside the lock chamber

e. FIFO Ready-to-Serve operating policy, whereby each cut of multicut lockages would lock as a powered single, but where knockout and setover lockages would continue to break and recouple inside the chamber

Description of Switchboat Operations

107. All of these operating policies would require the permanent and continuous presence of one or more switchboats at the locks. Multicut tows would be allowed to enter either chamber as usual, break apart within the chamber, and back out so that the unpowered cut could be locked. The unpowered cut(s) would be extracted by a switchboat and moved to a mooring area a sufficient distance from the lock to prevent recoupling operations from interfering with the operations of the lock.

The lock could be turned back, and the powered cut of a double lockage tow could begin locking while the switchboat is moving the first cut to the reassembling area. The switchboat would then travel back to the lock to assist the next lockage when required, either in the main or auxiliary chamber. For the cases involving extended lower lock walls, tows traveling in the same direction would be locked sequentially, so that the lock could be turned back to service a waiting tow while an exiting tow is recoupling on the wall. Setover and knockout size tows would continue to be reconfigured at the lock chamber, but following lockage, they would travel to a nearby reassembling area, with help as needed from a switchboat, for remaking to their original configurations.

Simulation of Switchboat Operations

108. In general, the operations envisioned would permit tows to uncouple inside the lock but not to recouple there following the lockage process. Tows would remake in a mooring area far enough away to prevent interference with subsequent lockage operations. Thus double (or more), setover, and knockout lockages would be permitted, but a significant time savings could be recognized by eliminating the recoupling process at the lock. The FIFO Ready-to-Serve policy is similar to what has been called "switchboat operations," except that the unpowered cuts of multi-cut tows would be powered through the locking process by a switchboat; e.g., each double will become two single lockages.

109. Switchboat operations can be simulated by the WATSIM model by simply reducing the chamber processing times of the double, setover, and knockout lockages, as appropriate. Following lockage, the setover and knockout tows would travel under their own power with help from a switchboat, if necessary, to the mooring area before remaking into their run-of-the-river configurations. The lock processing time distribution for single lockages would remain the same in the model because there would be no change in their current locking procedures. Modifications were made to the model during previous studies to enable the direct

simulation of the FIFO Ready-to-Serve policy without revising the lockage times frequency distributions.

110. The WATSIM model defines the chamber processing time as the period from the crossing of the lock sill by the tow's bow upon entry to the crossing of the opposite sill by the stern during exit. The use of switchboats at Gallipolis would reduce the chamber processing time of double lockage tows for the following primary reasons:

a. An unpowered cut would be extracted from the lock by a switchboat rather than a winch.

b. Powered and unpowered cuts would not be recoupled inside the lock.

This more efficient utilization of the lockage facilities would result in less delay time for waiting tows.

111. Setover- and knockout-type lockages would continue to be locked by a single chamber filling or emptying operation after each tow had completed uncoupling and reconfiguring for lockage. These tows would exit under their own power with assistance provided by the switchboat to the reassembling area and remake there without further requirements for use of the lock chamber. The time savings to be recognized from the switchboat assists would primarily come from elimination of the recoupling operation at the lock, with perhaps a small increase in exit time while the switchboat positions itself behind and attaches to a setover or knockout as it exits. If required, however, switchboat assistance in traveling to the mooring area would enable a faster and safer departure of setover- and knockout-type tows.

Derivation of Chamber Processing Times for Simulation of Switchboat Operations

112. If switchboat operations are initiated at Gallipolis, the normal chamber processing times for double, setover, and knockout lockages are estimated to decrease by the amounts shown in Table 18. Since WATSIM lockage component time distributions are in terms of whole numbers, with the times for setover- and knockout-type lockages combined, a summary table of the time reductions actually input to WATSIM is given

at the bottom of Table 18. The reduced times resulting from the extraction of unpowered cuts of doubles with the help of a switchboat (from the top of Table 18), in lieu of winching, were obtained from the data reported by Peat, Marwick, Mitchell & Co. (PMM&Co) in their report "Evaluation of Operational Improvements at Locks and Dam No. 26, Mississippi River."[4] Timing data were taken at Locks and Dam 26 during base periods when unpowered cuts of doubles were winched from the chamber and later as switchboats were used. Such operations at Locks and Dam 26 would closely resemble the same operations at Gallipolis. Thus the time savings shown in Table 18 for this activity were obtained directly from the Locks and Dam 26 tests. Greater time savings would be experienced by the downbound tows because the winching operation takes longer in the lower pool. The reason for this is that the position of unpowered cuts further below the top of the lock wall (where the winch is located) prevents the winch from making a straight pull.

113. Time savings associated with the elimination of recoupling inside the chambers were estimated by use of the 12 months of PMS data taken from October 1975 through September 1976. The time required to recouple each double, setover, or knockout tow was recorded as part of the exit time, according to the rules for recording PMS data. The recoupling time of a tow can thus be closely approximated by determining the difference between a tow's exit time and the exit time of a single lockage tow (which, of course, does not require recoupling). The time required by doubles, setovers, and knockouts to actually move out of the chamber following recoupling and away from the lock is approximated by the exit time of a single tow, and thus the subtraction of a single tow's exit time would leave only the time required to recouple.

114. The recoupling times computed in this manner are shown by lock chamber (main and auxiliary), direction of travel, and exit type (turnback, exchange, or fly) in Tables 19-24. Because data on turnback- and exchange-type exits in the auxiliary chamber is limited, the fly exit times had to be used to compute the recoupling times of tows using this chamber. As an example of how the data shown in Tables 19-24 were used, the average difference between double and single turnback exit

times for upbound tows is shown in Table 19 to be 14.3 min for the 12-month period. The corresponding average difference in the exchange exit times shown in Table 20 is 14.5 min. The resulting average of these two numbers is 14.4 min, as shown in Table 18, for double lockages of upbound tows in the main chamber. The time reductions associated with the elimination of recoupling operations inside the lock were derived for other lockage types in this manner. Computations of this type were also made for the auxiliary chamber, as shown in Tables 23 and 24, using only the recorded data for fly-type exits. Time reductions of a comparable magnitude were reported at Locks and Dam 26 by PMM&C in Reference 4.

Switchboat Operations in the Upper Pool Only

115. An initial series of simulation model tests were run to determine what the capacity of the locks would be if switchboat operations were employed only in the upper pool. This would be a logical interim means of decreasing lock processing times. Since tows usually approach the moored, decoupled, unpowered cut during recoupling operations by driving into the current, they would already be oriented upbound upon exit and could proceed directly toward the unpowered cut. Preliminary analysis indicates that the most probable location for mooring facilities in the upper pool would be at or slightly above mile 278 along the Ohio bank.

116. To simulate switchboat operations in the upper pool only, the chamber processing times of upbound doubles, setovers, and knockouts were appropriately reduced, as explained earlier. Reductions to setover and knockout lockage times were made together on a weighted average basis since the model combines these two frequency distributions of lockage component times. The significant output produced by the WATSIM model for switchboat operations in the upper pool is shown in Table 25 for three alternate operating policies. These data can be readily compared with corresponding data for base conditions in Table 12. The data in Table 25 were plotted and curves fit to match exponential and linear functions as shown in Figures 14-19.

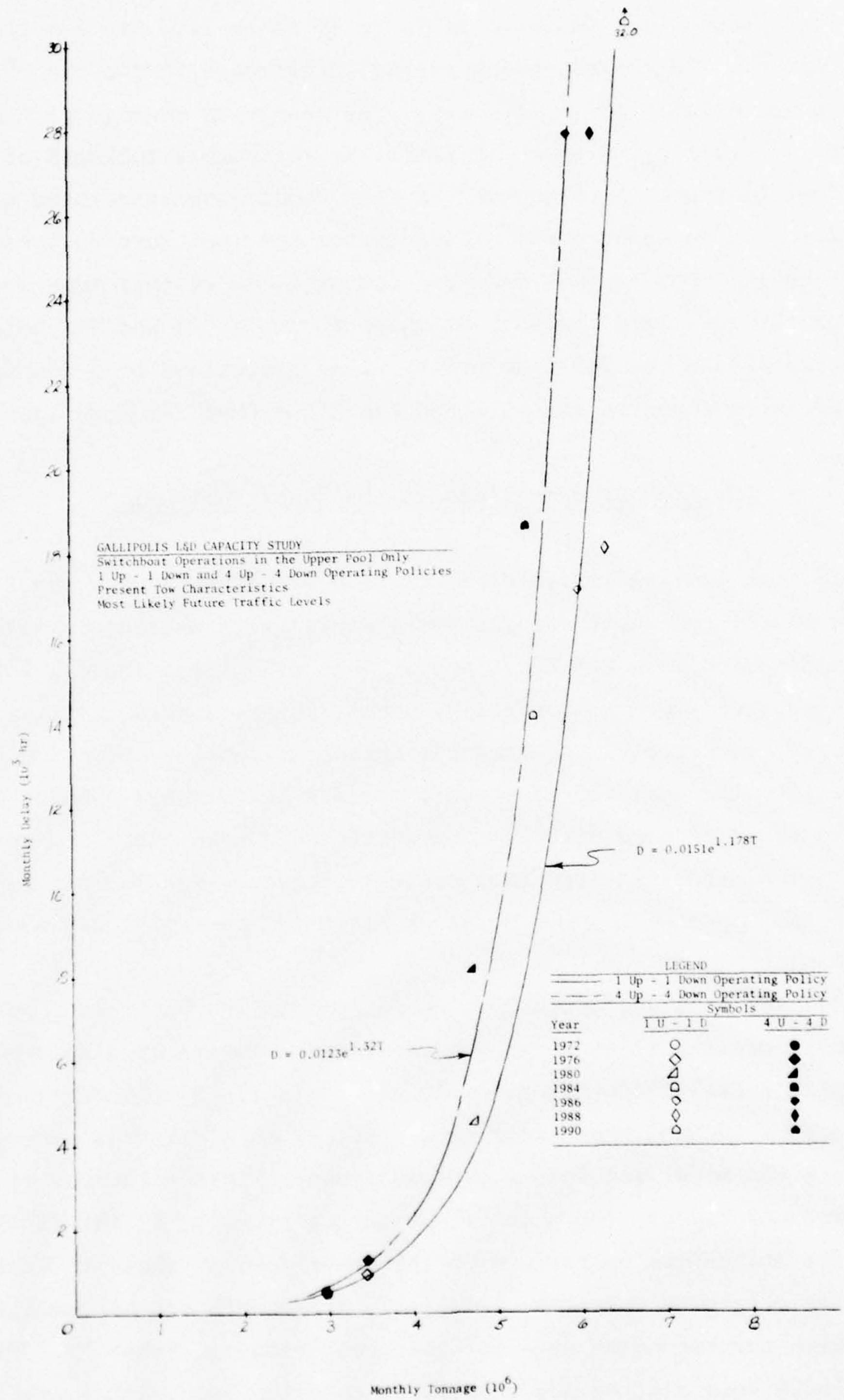


Figure 14. Monthly delay versus monthly tonnage for the 1U1D and 4U4D operating policies with switchboat operations in the upper pool only

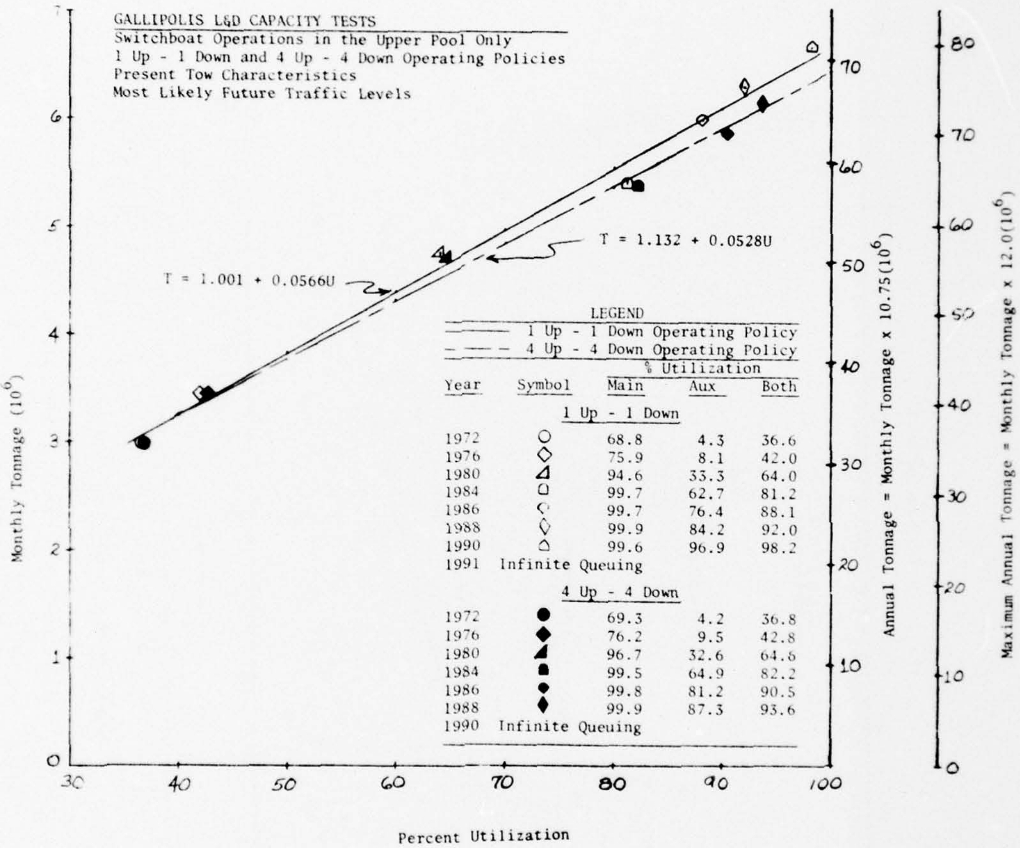


Figure 15. Monthly tonnage, annual tonnage, and maximum annual tonnage versus lock utilization for the 1U1D and 4U4D operating policies with switchboat operations in the upper pool only

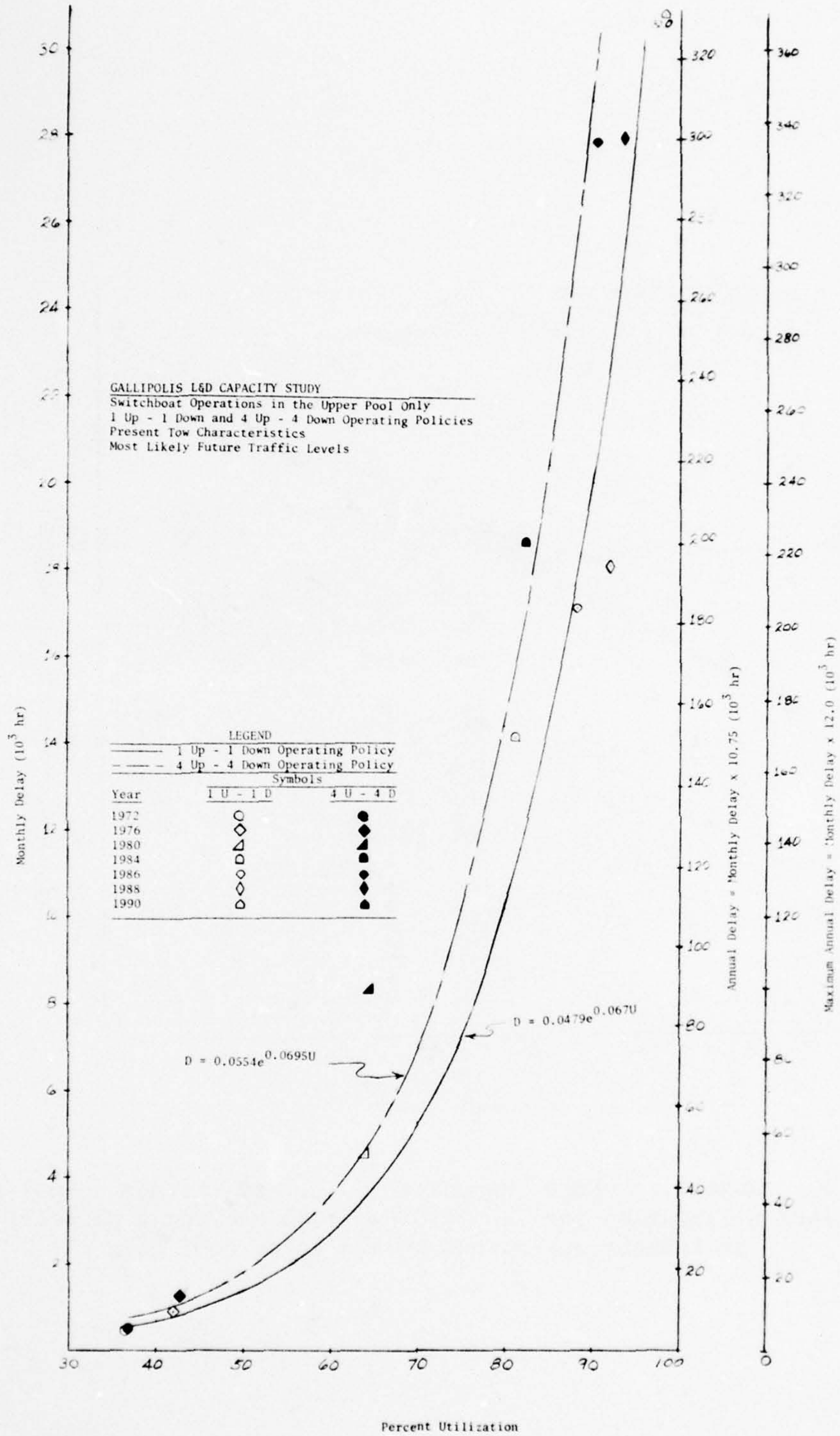


Figure 16. Monthly delay, annual delay, and maximum annual delay versus lock utilization for the 1U1D and 4U4D operating policies with switchboat operations in the upper pool only

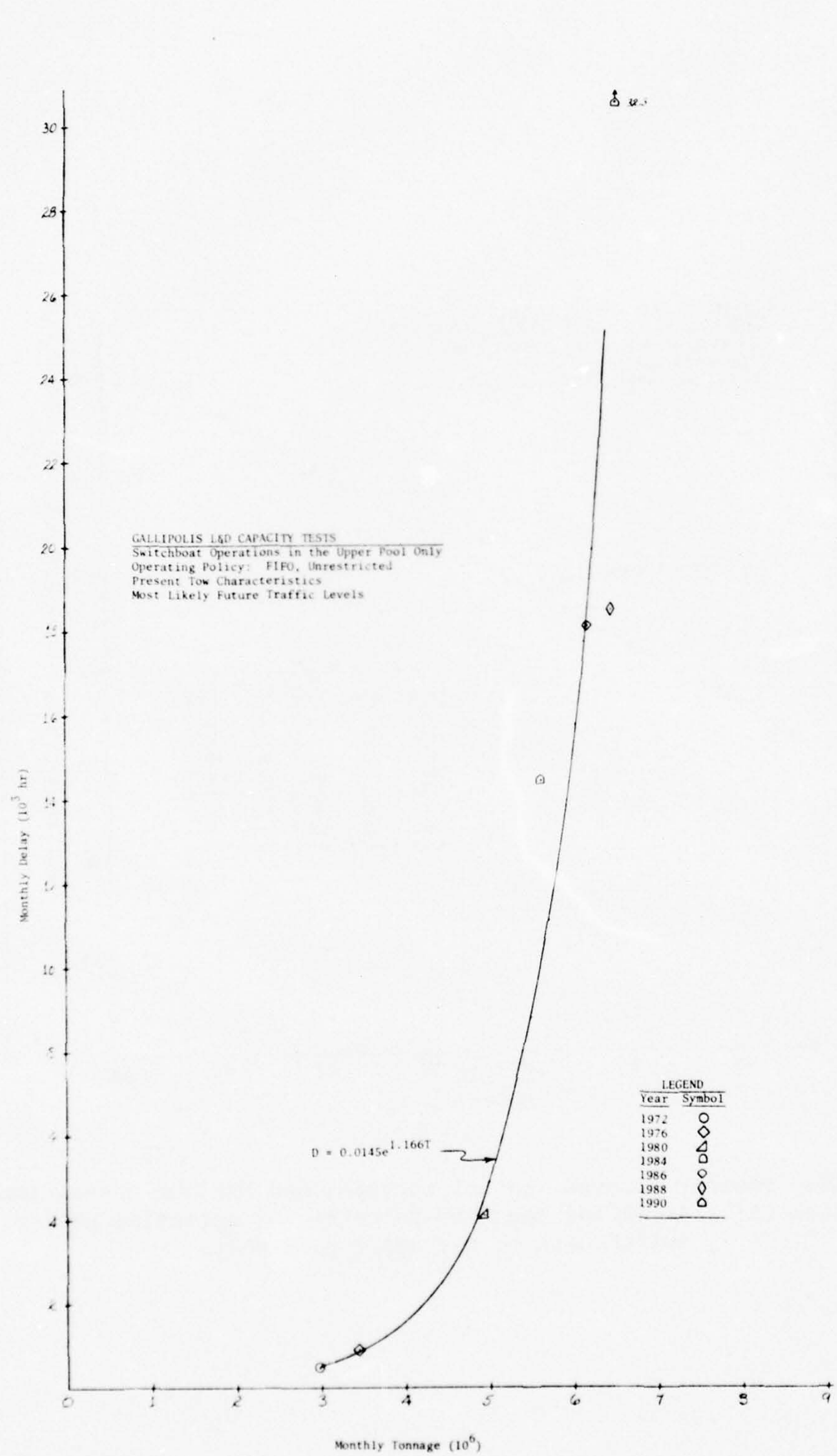


Figure 17. Monthly delay versus monthly tonnage for the FIFO Unrestricted operating policy with switchboats in the upper pool only

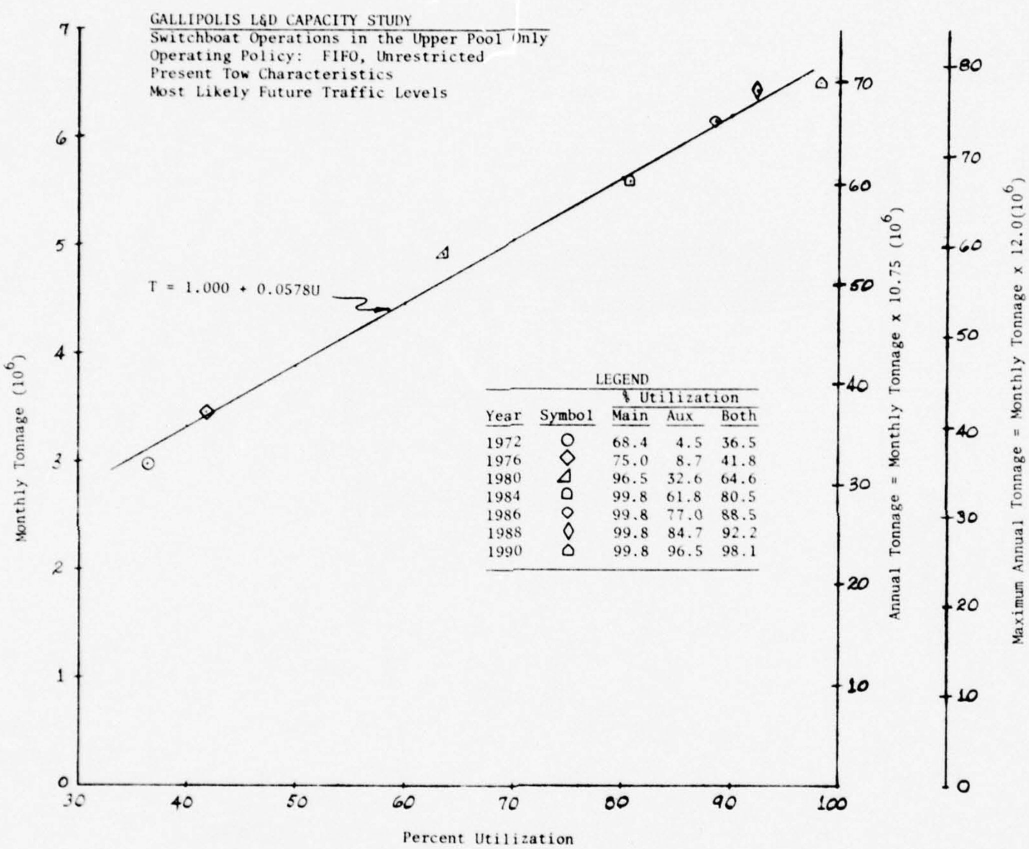


Figure 18. Monthly tonnage, annual tonnage, and maximum annual tonnage versus lock utilization for the FIFO Unrestricted operating policy with switchboats in the upper pool only

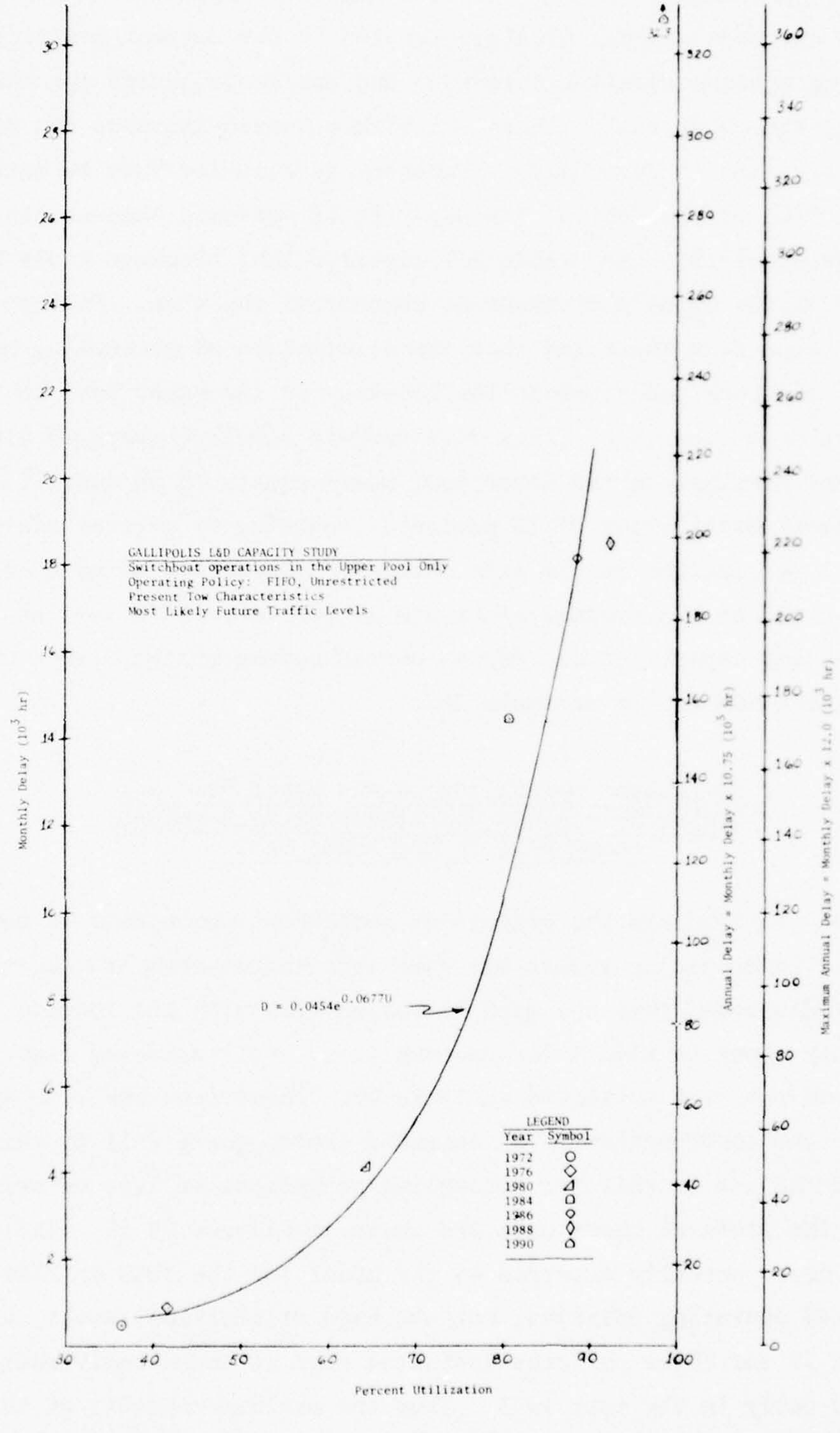


Figure 19. Monthly delay, annual delay, and maximum annual delay versus lock utilization for the FIFO Unrestricted operating policy with switchboats in the upper pool only

117. Use of switchboats in the upper pool would eliminate the additional approach channel blockage created by the current practice of recoupling upbound doubles, setovers, and knockouts inside the chamber and along the guide walls. This, in effect, would increase the potential utilization of the auxiliary chamber by allowing tows to enter into and exit from it more often. An analysis of approach channel blockage during December 1975 (see Table 16) revealed that blockage would have occurred in the upper pool about 56 percent of the time. Further analysis of these data indicated that the elimination of recoupling operations at the lock would reduce the blockage in the upper pool to about 34.5 percent of the time. This 34.5 percent blockage averaged with the 55 percent blockage in the lower pool would equate to an overall auxiliary chamber utilization of 55 percent. Assuming 95 percent maximum practical utilization in the main chamber, utilization of both locks as a whole would be the average of 95 and 55 percent, or 75 percent. The expected lock capacities and delays corresponding to this level of utilization are summarized in Table 26.

Switchboat Operations in the Upper Pool and Either Switchboat Operations or an Extended Guard Wall in the Lower Pool

118. To simulate the effects of switchboat operations in both the upper and lower pools, reductions were made to the chamber processing times of downbound tows and used in conjunction with the reduced times previously input to WATSIM for upbound tows. Data obtained from these simulation runs are presented in Table 27. These data are also applicable to the construction of an extended center guard wall in the lower pool and the use of this for recoupling operations in lieu of switchboats. The plots of these data are shown in Figures 20-25. Infinite queuing never actually occurred in the model for the 1U1D or FIFO Unrestricted operating policies, but the high utilization levels shown in Table 27 for these policies indicated that it undoubtedly would have occurred early in the year 1993. Thus the maximum capacity of the lock was, for all practical purposes, established by the 1992 run. However,

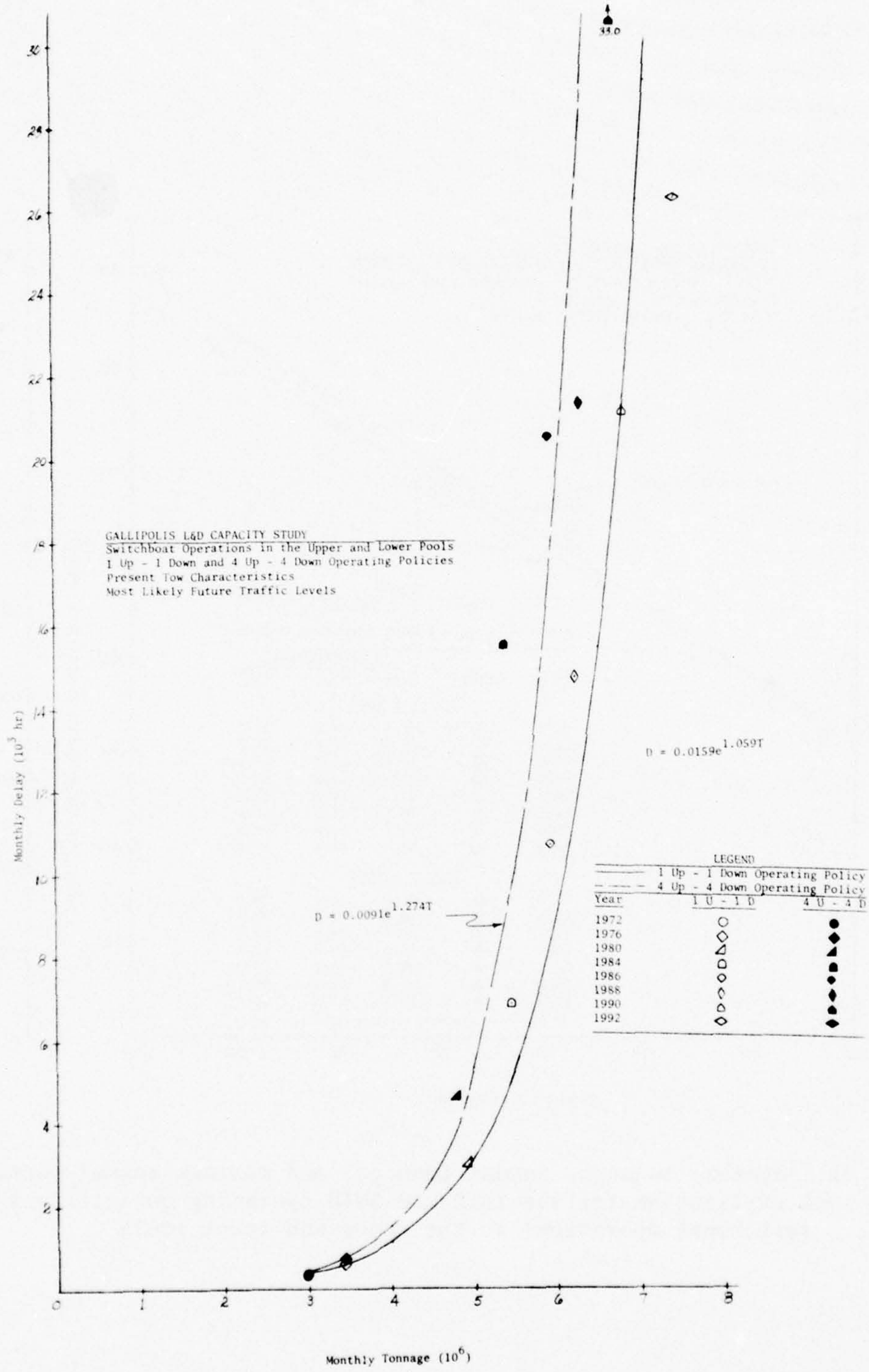


Figure 20. Monthly delay versus monthly tonnage for the 1U1D and 4U4D operating policies with switchboat operations in the upper and lower pools

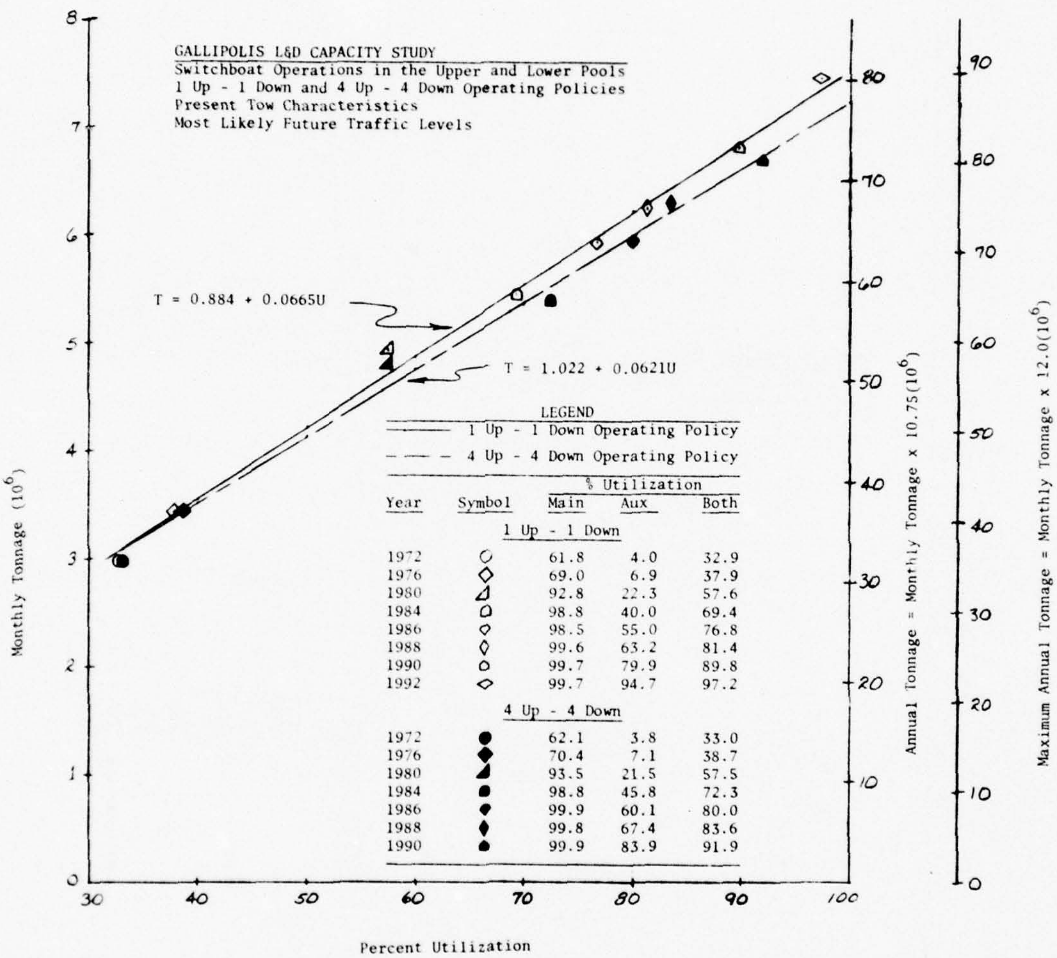


Figure 21. Monthly tonnage, annual tonnage, and maximum annual tonnage versus lock utilization for the 1U1D and 4U4D operating policies with switchboat operations in the upper and lower pools

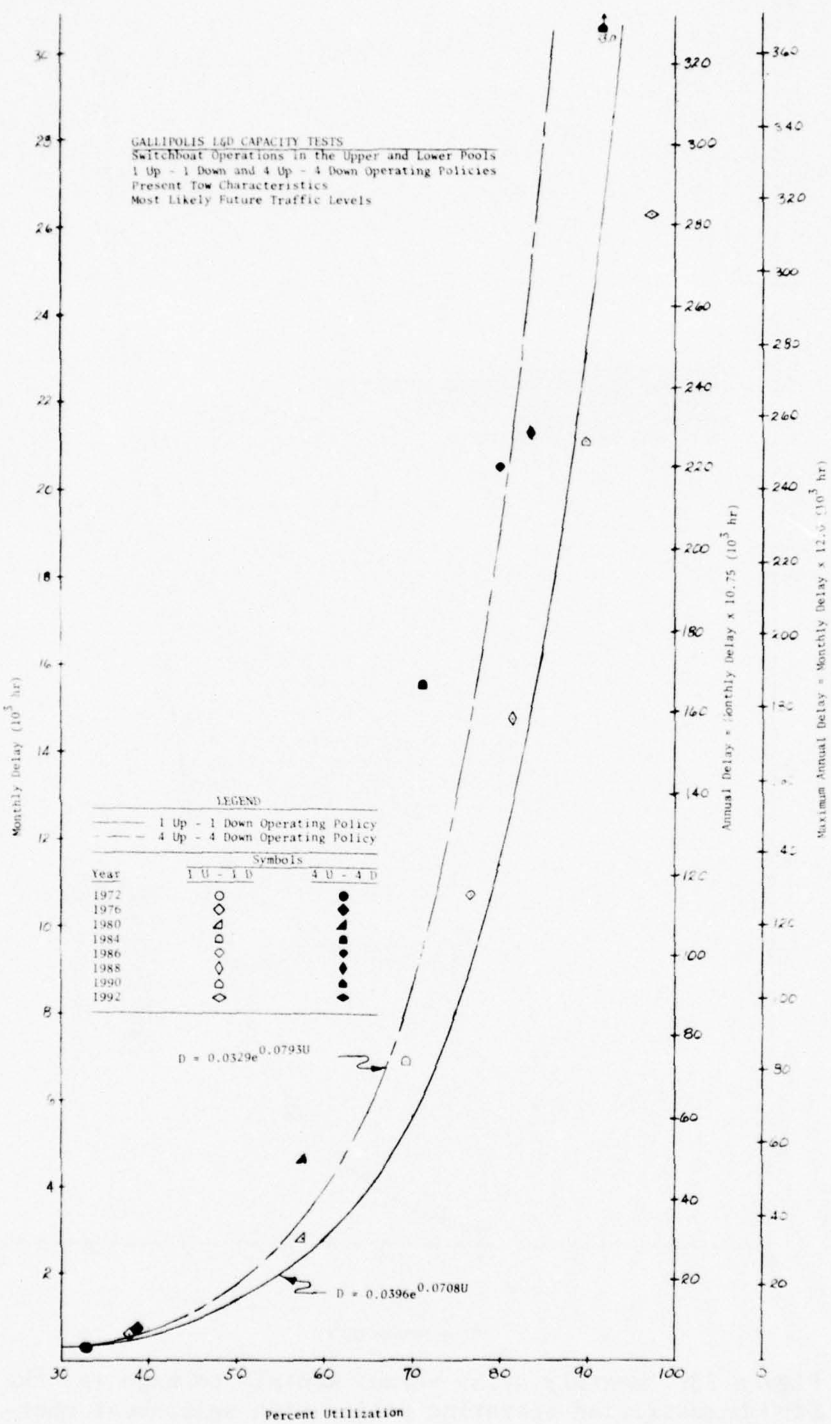


Figure 22. Monthly delay, annual delay, and maximum annual delay versus lock utilization for the 1U1D and 4U4D operating policies with switchboat operations in the upper and lower pools

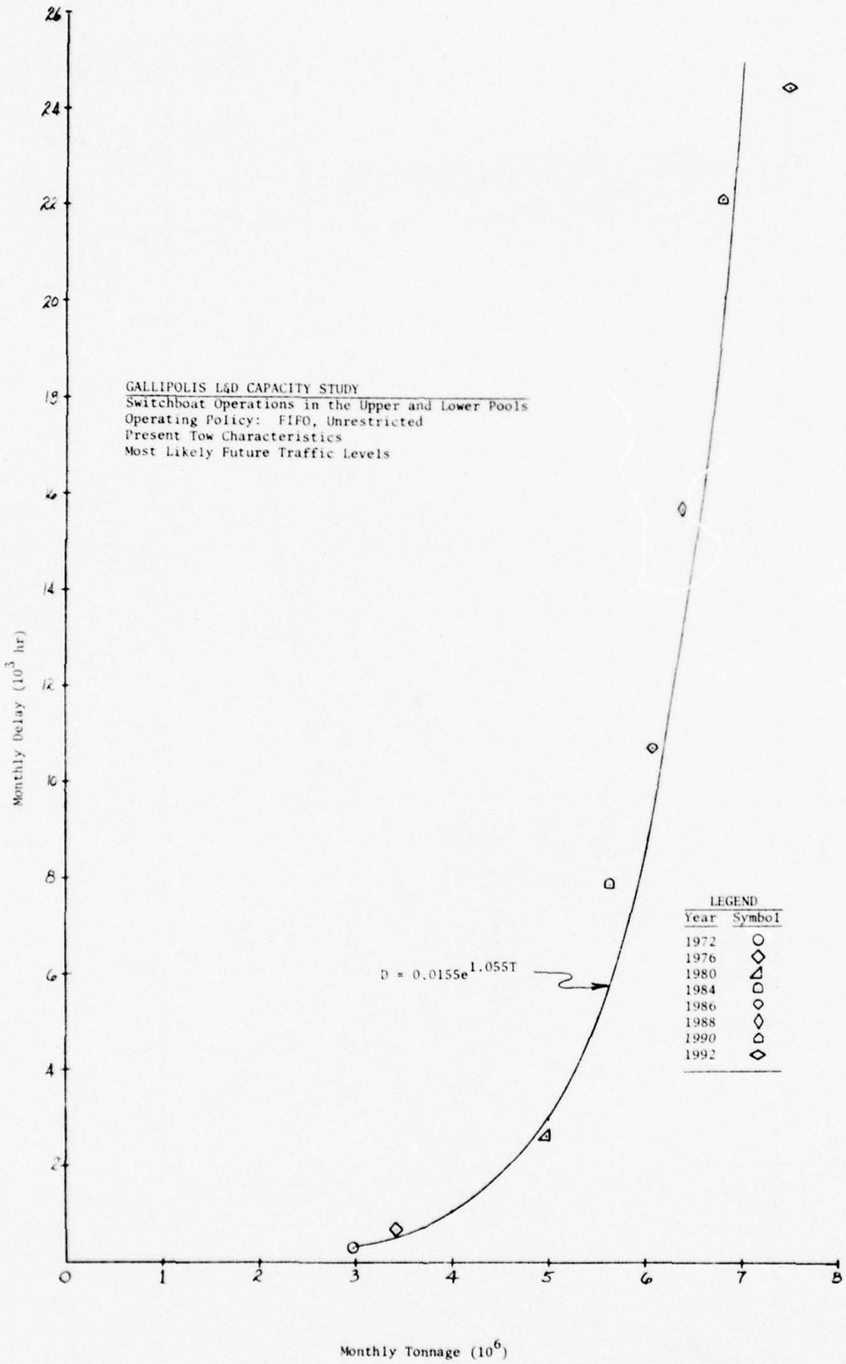


Figure 23. Monthly delay versus monthly tonnage for the FIFO Unrestricted operating policy with switchboat operations in the upper and lower pools

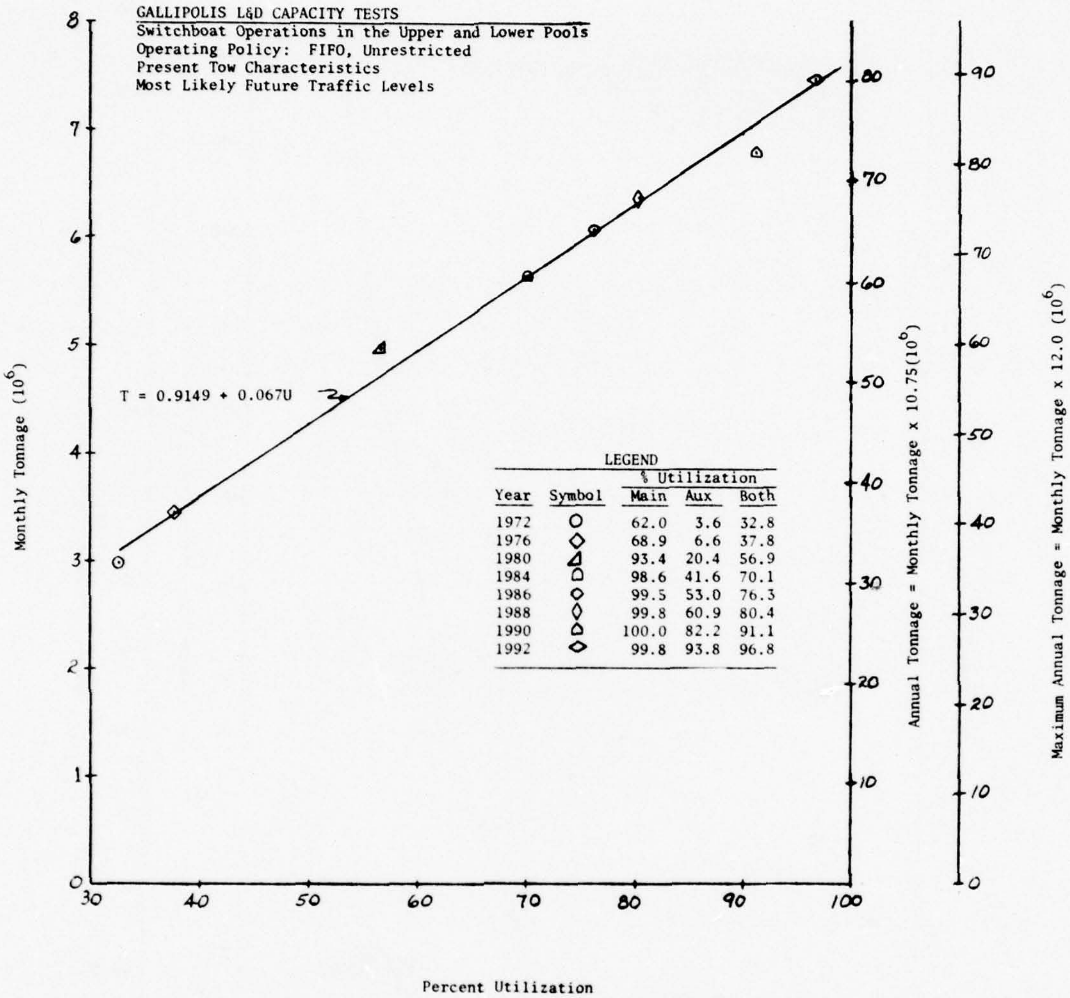


Figure 24. Monthly tonnage, annual tonnage, and maximum annual tonnage versus lock utilization for the FIFO Unrestricted operating policy with switchboat operations in the upper and lower pools

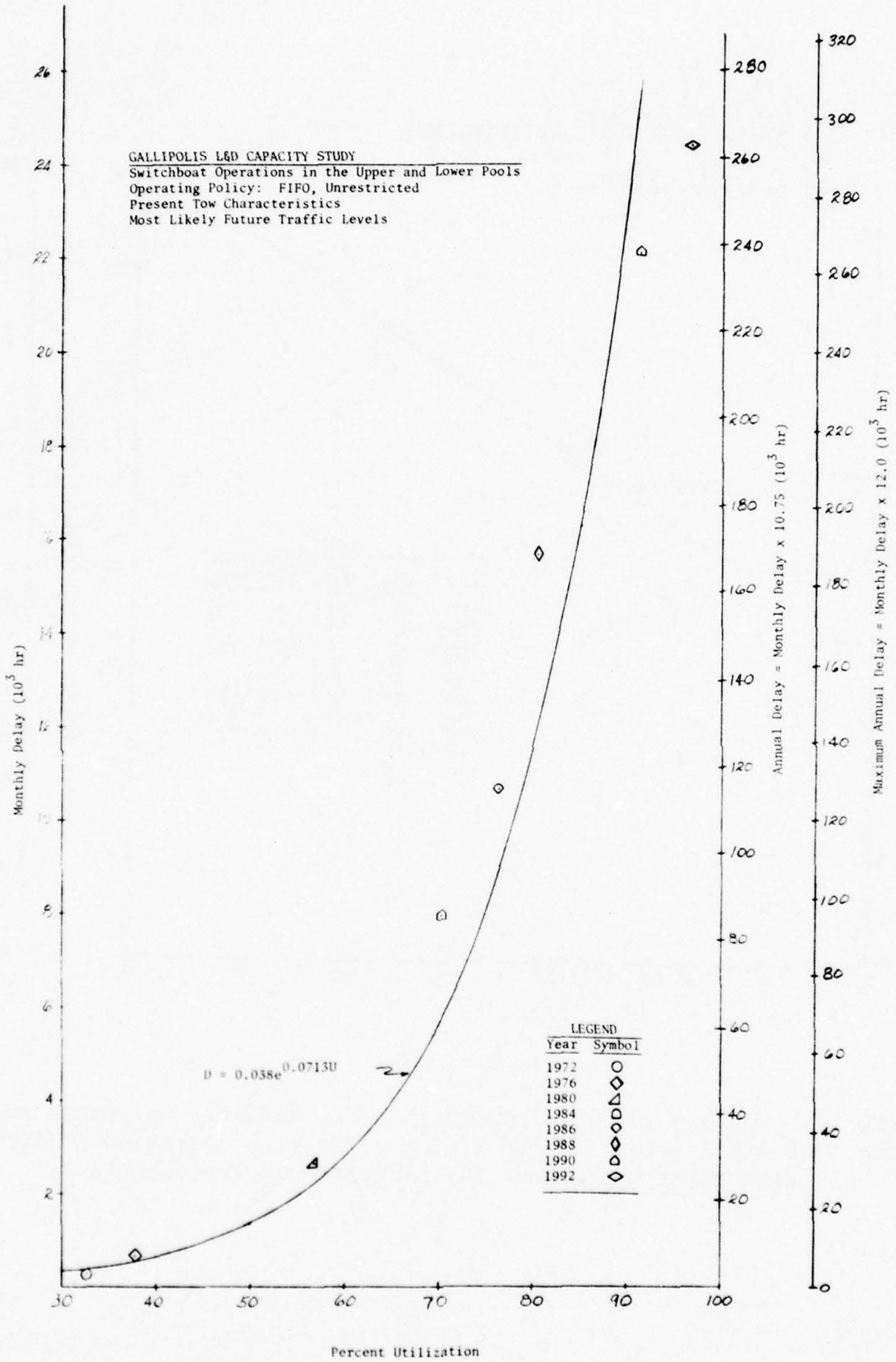


Figure 25. Monthly delay, annual delay, and maximum annual delay versus lock utilization for the FIFO Unrestricted operating policy with switchboat operations in the upper and lower pools

such high levels of utilization would not be possible even after the necessary improvements to the existing lockage facilities were made.

119. For this operating situation at the lock, entry channel blockage occurs as all tows enter and exit and also as doubles, setovers, and knockouts break apart for lockage. In addition, the powered cut of each double would block one side of the approach channel while the unpowered cut was being locked, while the lock turned back to service the powered cut, and during its short entry. Further analysis of the December 1975 data indicates that the use of switchboats (or an extended center guard wall) in the lower pool would reduce channel blockage below the locks from 55 percent to only 37.7 percent of the time. This, averaged with the earlier computed 34.5 percent blockage in the upper pool, equates to an estimated utilization for the auxiliary chamber of 64 percent. The combined utilization for both locks is therefore the average of 95 percent and 64 percent, or about 80 percent. The practical tonnage capacities and delays shown in Table 28 for three different operating policies correspond to this 80 percent level of utilization with appropriate adjustments to compensate for differences in the WCSC and lockmaster's tonnage data. Reasons for this adjustment in practical lock capacity were given earlier in paragraph 105.

120. The 4U4D policy was simulated in lieu of the 3U3D policy because of its potential for future adoption if the center guard wall in the lower pool is extended to enable tows to recouple outside the lock chamber without delaying lock turnback (Figure 26). Since about 75 percent of the tows using the Gallipolis main chamber require a double lockage, the 4U4D policy would improve the probability of having a smaller tow available to lock as the fourth tow of the series. Tows requiring only a single lockage would not need to be recoupled on the guard wall, and thus the first of a series of four tows traveling in the opposite direction could begin its entry much sooner. The extension of the lower center guard wall may prove more feasible than switchboat operations in the lower pool because of the safety aspects involved in maneuvering large tows in the reassembling area. Unfortunately, however, lock operations could be delayed or curtailed for long periods during

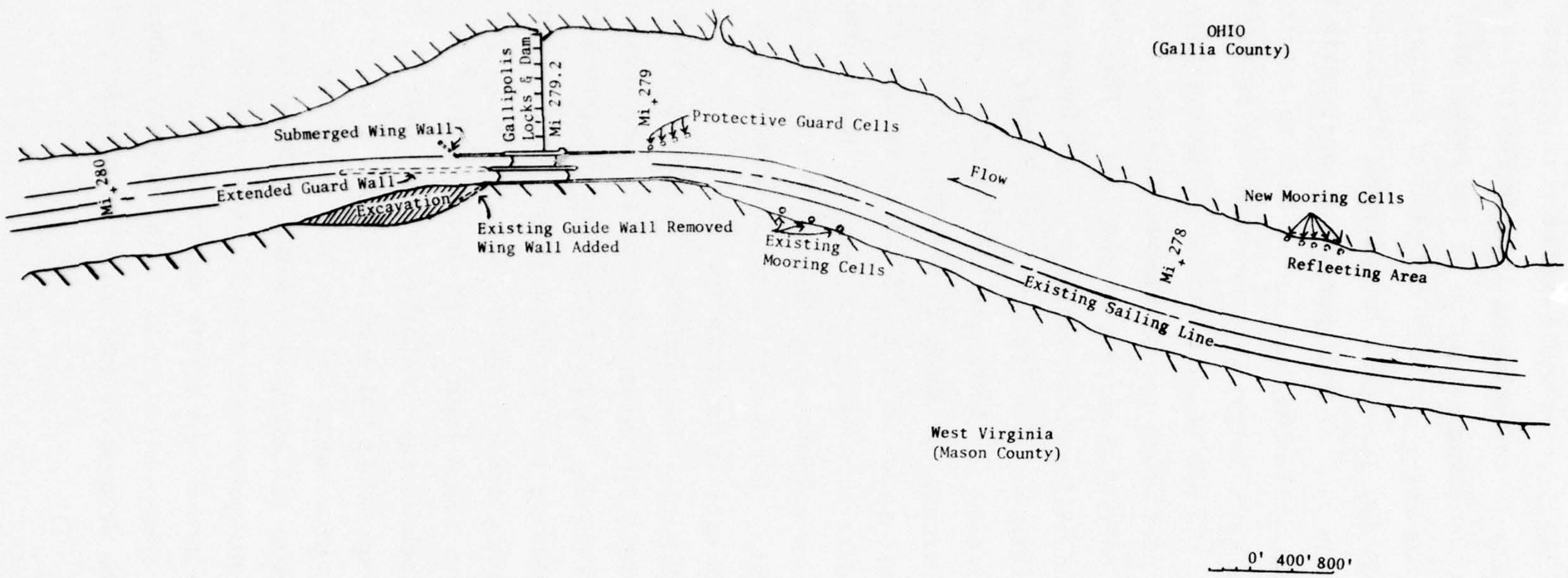


Figure 26. Proposed improvements to existing site, Gallipolis Locks and Dam, Ohio River

the construction of this wall. Further engineering studies are required to determine which of these approaches would be best. Such studies are being conducted by the Huntington District.

121. There are some specific disadvantages, in terms of safety and industry desires, to reassembling barges outside the lock chamber, especially in the lower pool. Reassembling in the downstream mooring area could be hazardous because of the required tow maneuvers. The tows usually approach a moored cut when heading upstream. Since they will be headed downstream upon exit, each tow would have to turn 180° in midstream. They would then approach the moored cut from downstream, recouple, and execute another 180° turn with the full tow.

122. As discussed above, an alternative to reassembling in the downstream approach is the extension of the guard wall located between the two chambers and the construction of other works for improving navigation at the locks, as shown in Figure 26. This wall could be used by downbound tows for reassembling without interfering with operations in the auxiliary chamber. The effective capacity of the locks with the extended center guard wall and other possible improvements, if desired, is estimated to be about the same as employing switchboats in the lower pool. However, in order to achieve this capacity with the lower guard wall extension, the last of a series of one-directional lockages should be a single lockage in order to minimize delay to the tow approaching from the opposite direction.

123. Careful consideration has been given to all the possible alternative improvements that could be made at Gallipolis. Discussions with a number of different engineers at both WES and the Huntington District were held before the most feasible structural improvements shown in Figure 26 were determined. The upper approach should be improved by placing guard cells angled toward the center of the river upstream from the river guard wall. These cells would be spaced so as to prevent a tow or small boat from passing through the space between the cells but far enough apart that the water flow would pass through them. The cells would provide tows protection from being swept by the current around the end of the river guard wall and into the gates of the dam.

The angle of the cells should be such that tows will have an adequate maneuvering area for approaching the locks. There would be mooring cells at a reassembling area in the upper pool on the Ohio bank above mile 278.

124. The center wall (see Figure 26) should be extended in the downstream pool to a length of about 1500 ft. This wall would serve as a guide wall for tows entering the auxiliary chamber and as a guard wall for tows entering the main chamber. Downbound tows requiring double lockages could use this wall for reassembling since it is long enough for an entire tow to moor along the wall and clear the miter gates and the filling and emptying system outlets. Therefore no reassembling area would be required downstream, and the tows would not have to execute the hazardous 180° turns in midriver, as mentioned earlier. The center wall could be constructed of cells, or possibly DeLong piers, like those used at Locks and Dam 26 on the Mississippi River, could be used. If possible, a winching system should be installed to remove the unpowered cuts of downbound double lockage tows. That way the switchboat could remain in the upper pool and assist tows entering and leaving the locks. If necessary, the switchboat could lock through the auxiliary chamber and be available to pull these cuts to the end of the center wall. The landward guide wall would probably have to be removed and the West Virginia bank area near the main lock entrance excavated to provide an adequate maneuver area for tows entering the main chamber. A submerged wing dike could be constructed off the end of the downstream river guard wall on the auxiliary chamber to reduce the current toward the center guide wall and the shoaling in the approach channels.

Switchboat Operations in the Upper Pool and an Extended Landward Guide Wall in the Lower Pool

125. There is concern that locking activities at Gallipolis would be disrupted during the construction of the proposed 1500-ft lower guard wall extension between the two chambers. To prevent prohibitive delays to tows, an alternative, though less effective, means of increasing lock capacity could be the extension of the existing downstream guide wall

along the riverbank. Disruption of locking activities during the construction period would be minimal; and after the wall is completed, downbound multicut tows, setovers, and knockouts would recouple adjacent to the wall without delaying the turnback of the lock. However, the recoupling of tows on the extended landward guide wall would block the entry or exit of other tows waiting to use, or being processed by, the auxiliary chamber. The lower approach would be blocked about 55 percent of the time, as determined from the analysis of December 1975 data; but in the upper pool, where switchboat operations are assumed to take place, the channel blockage would be only about 23 percent. Lock utilization associated with this alternative operating condition was computed to be about 55 percent for the auxiliary chamber and 75 percent for both chambers combined. Tonnage levels and delays corresponding to this percent of utilization were obtained from the plots for switchboat operations in the upper and lower pools as given in Table 29.

FIFO Ready-to-Serve Operating Policy

126. As would be expected, significant increases in the capacity of the locks could be attained if the FIFO Ready-to-Serve policy is possible. The policy would require that all multicut tows using the lock configure themselves as straight singles. In other words, doubles would not be permitted to lock as they now do under the current inefficient policy. The Ready-to-Serve policy does, however, assume that setovers and knockouts would continue to reconfigure at the locks. Since unpowered cuts of doubles would no longer be moored to the lock walls, entry to and exit from the auxiliary chamber would not be blocked as often, thus increasing its utilization potential. The approach channel would be blocked during the approach and exit of tows using the main chamber and when setovers and knockouts broke apart and recoupled, but not during the long periods required to break and recouple multicut tows inside the lock chamber.

127. The significant output from the simulation model is given for the FIFO Ready-to-Serve operating policy in Table 30. Figures 27-29

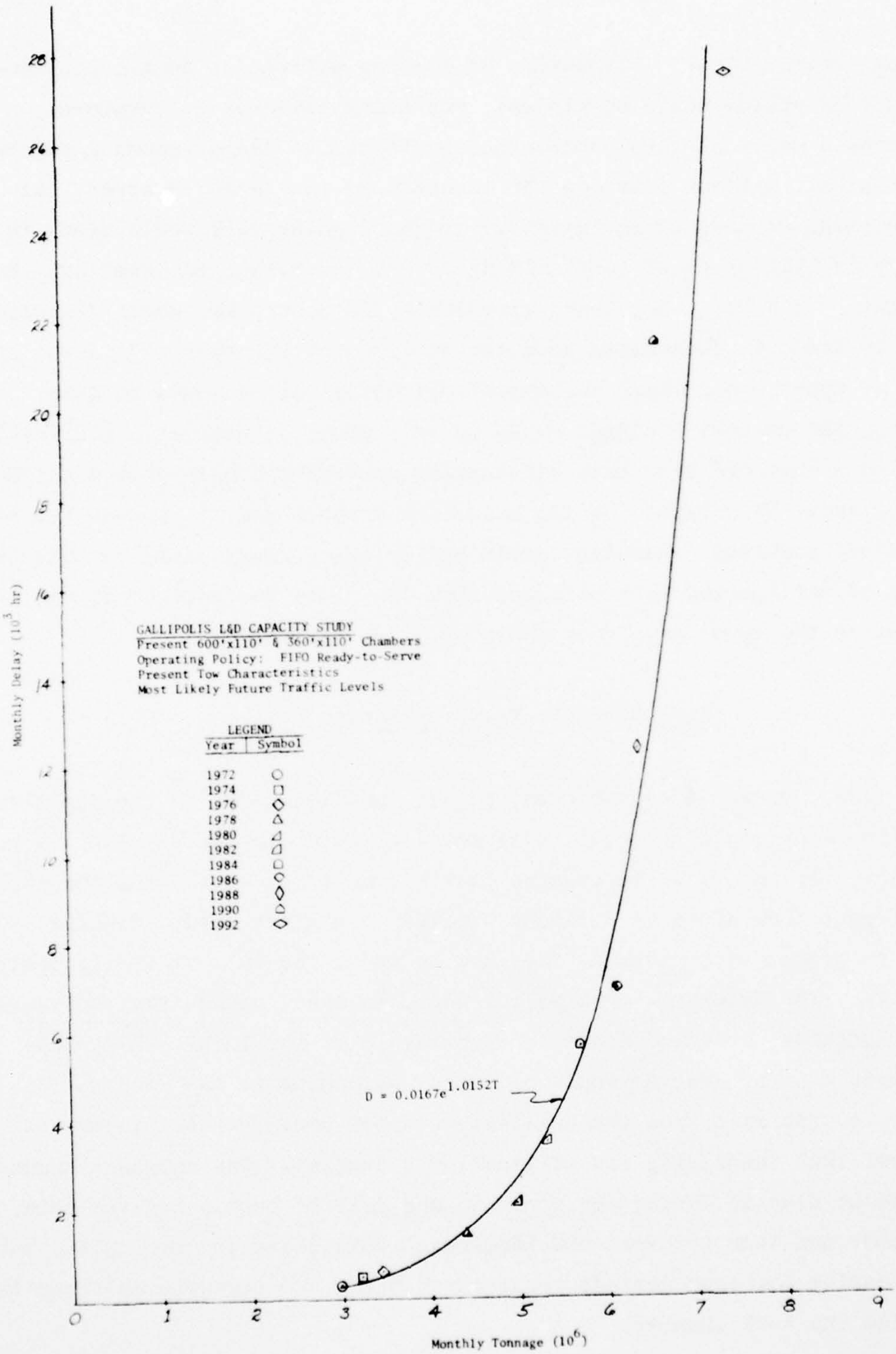


Figure 27. Monthly delay versus monthly tonnage for the FIFO Ready-to-Serve operating policy

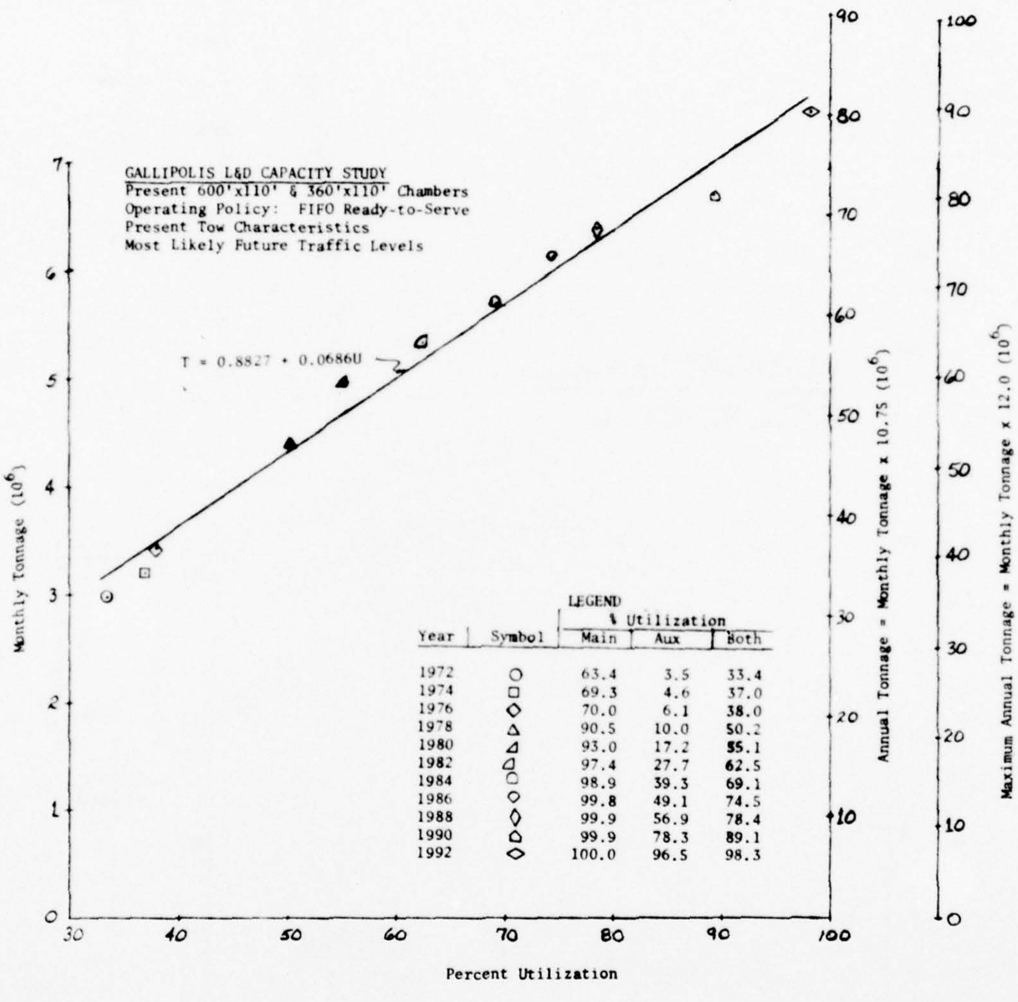


Figure 28. Monthly tonnage, annual tonnage, and maximum annual tonnage versus lock utilization for the FIFO Ready-to-Serve operating policy

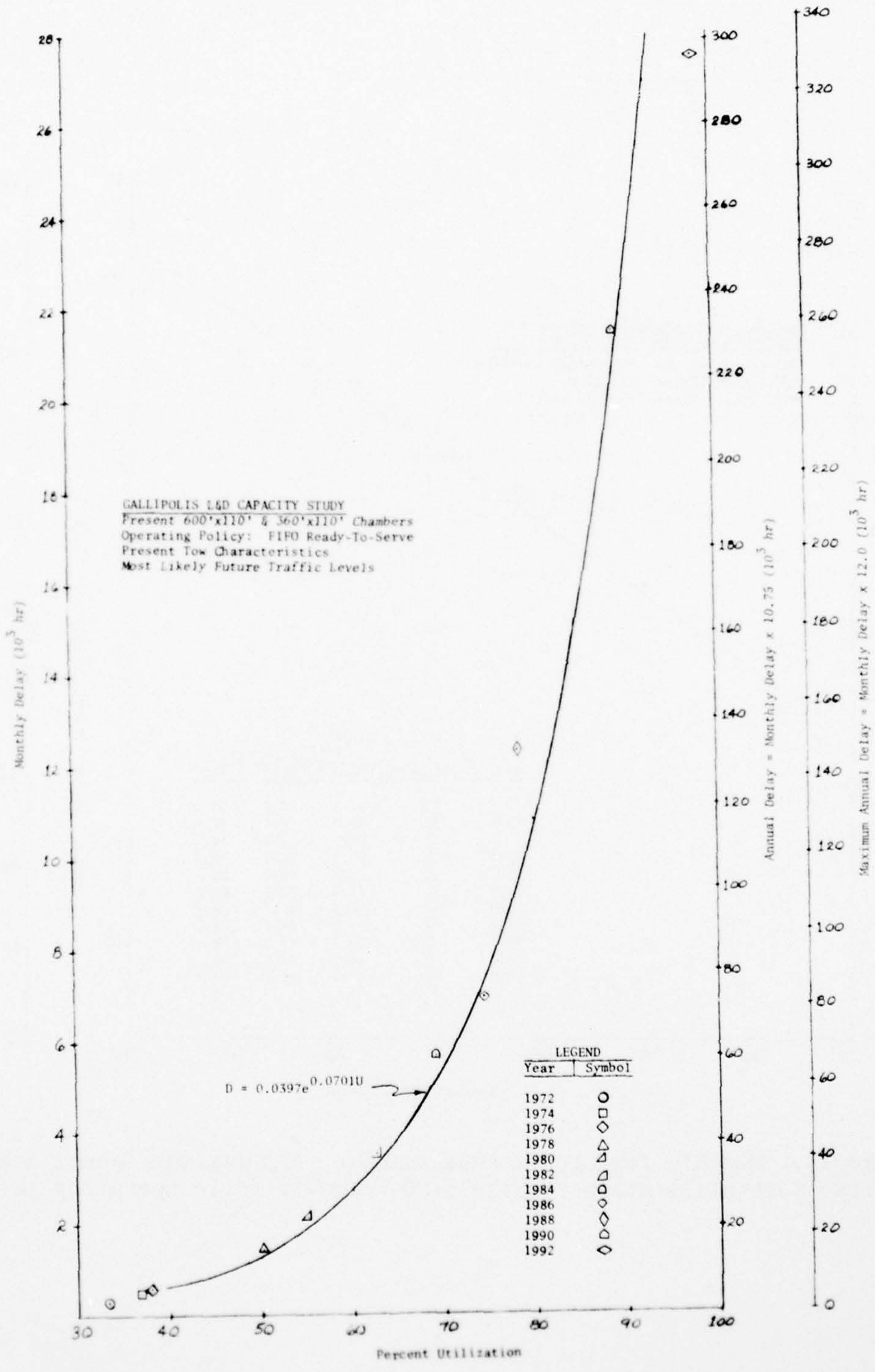


Figure 29. Monthly delay, annual delay, and maximum annual delay for the FIFO Ready-to-Serve operating policy

graphically illustrate the results of the model output. Figure 28 indicates that at very high levels of utilization, the monthly throughput for both chambers could approach 7 million tons. However, because of continued interference from simultaneous operations in both chambers, utilization levels above the 85 percent range probably could not be reached. This was the level of utilization computed by use again of the December 1975 data and allowance for entry channel blockage as all tows entered and exited (doubles counted as 2 singles) and also as knockouts and setovers reconfigured in the lock approaches during the lockage process. A summary of lock utilization, tow delays, and adjusted practical tonnage capacity levels is given in Table 31. The footnotes on Table 31 give appropriate information on the data presented. The Ready-to-Serve operating policy was not tested under the N Up-N Down rule because all previous experience has indicated that given the same tow list and lockage component times in the model, the FIFO order of call-up is always more efficient in terms of reduced delays and increased tonnages. This was true for all model runs during this study and therefore would also hold true for the Ready-to-Serve policy if simulation runs of the N Up-N Down policy were actually made. Only if, for example, lock swing-around time was reduced in the model to compensate for reduced differences in water elevations during high flows, would the N Up-N Down policy be beneficial, and then only if provisions were made to prevent the excessive blocking of the entrance to and exit from the auxiliary chamber. The N Up-N Down rule is currently used at the discretion of the lockmaster during periods of high water to reduce queue lengths. High water conditions at Gallipolis are discussed further in PARTS VI and IX of this report.

128. To place the Ready-to-Serve policy in effect, switchboats would be required at the locks at all times to assist the larger tows in their locking process. The switchboats would attach to separate unpowered cuts of large multicut tows and serve as the towboat until the barges have been moved to the mooring area on the opposite side of the lock. The cost of such operations in terms of equipment and manpower may make this alternative economically unfeasible. The possibility

exists for towboats to assist one another if insurance requirements and other obstacles to such assistance could be overcome. In any case, the construction of mooring and reassembling areas in the vicinity of the locks would be required.

Theoretical Maximum Tonnage Levels After Structural Improvements

129. The theoretical maximum tonnage capacities, computed as explained earlier in PART VI, are given in Tables 32-38 for all the alternative operating policies discussed in PART VII. As mentioned earlier, the computations shown in these tables are presented for the information of the reader only and are supplemental data for comparative purposes in analyzing the capacity of the Gallipolis Locks.

PART VIII: SCHEDULING TOWS FOR OPTIMUM UTILIZATION OF BOTH CHAMBERS

General

130. Because of their design and physical location in a river bend, the Gallipolis Locks cannot be operated as efficiently as most other locks. This is especially true of the smaller auxiliary chamber that at present is primarily used to service small tows, light boats, and pleasure craft. The processing of multiple lockage tows through the auxiliary chamber can block the entrance channel for excessive periods and prevent other tows from entering or departing the main chamber. However, as tow queues and associated costly delays increase in future years, there will be a greater incentive for more and larger tows to use the auxiliary chamber. Thus an analysis of potential ways to increase the utilization of the auxiliary chamber without adversely interfering with operations in the main chamber was considered to be an important part of this study. Of course, any such analysis must consider interference to tow entry-egress that could be caused by tows entering or exiting either chamber and by portions of tows moored on the guide walls or guard walls.

131. The proposal for initiating the Gallipolis capacity study stated that an analysis would be made of an operating policy for scheduling the use of the main and auxiliary chambers so as to efficiently use the upper and lower approach channels and minimize interference caused by a higher level of auxiliary chamber utilization. Since the WATSIM model does not have any programmed logic for simulating this procedure and since the undertaking to develop this capability would have been quite sizable, this operating alternative was analyzed by use of a hand-computational and graphic procedure to approximate the locking efficiency that could be obtained by scheduling the use of the approach channels.

Analytical Procedure for Scheduling Tows

132. If every effort is made to minimize interference with operations in the main chamber, there is still a considerable percentage of available time when operations in the main chamber block the entry and exit of tows using the auxiliary chamber. The magnitude of the interference times involved was analyzed using December 1975 PMS data and the results are reported in PART VI, paragraphs 95 and 96, of this report. As indicated, the December data revealed that tows could have entered into and exited from the auxiliary chamber only about 45 percent of the time, thus equating to a utilization of only 45 percent for this chamber, unless action is taken to schedule around the periods of channel blockage. If, however, tows could be selected from a waiting queue to effectively use the time available (when the approach channel is not blocked) to enter and exit from the lock and during periods when the channel is blocked by operations in the main chamber, to break, chamber, remake, and perform other processing operations that do not require approach or exit of the tow through the channel, then the auxiliary chamber might possibly be utilized more than 45 percent of the time.

133. A graphical and hand-computational procedure has been used to approximate the increased utilization of the auxiliary chamber, together with an associated main chamber utilization level, resulting from the selective lockage of tows waiting in queue. A slight reduction in the utilization of the main chamber was expected because of the high probability of some interference from increased operations in the auxiliary chamber. A queue length of 40 tows was selected at random from an available TOWGEN printout for projected traffic levels in the year 1984. The average lockage component times (approach, entry, chambering, etc.) for each of the 40 tows were derived from PMS data for the months of October and December 1975 and February, May, and August 1976. Separate lockage component times were developed for each chamber. The lock turnback time required between the two cuts of a double lockage was estimated using the average chambering time of singles with turnback exits. A continuous sheet of graph paper, similar to a strip chart

with the abscissa (x axis) representing time in minutes, was used to chart the steps involved in locking each of the 40 randomly selected tows through one of the lock chambers. The steps and times (minutes) involved in the locking process were represented on the chart for each chamber separately, but simultaneously, with the events occurring in the auxiliary chamber shown immediately above the events taking place concurrently in the main chamber. Thus the periods of channel blockage caused by operations in either chamber were graphically displayed so that each waiting tow could be selected at an opportune time for lockage in one of the chambers. The chart showed the times when the upper approach, the lower approach, or both were blocked by operations in either or both chambers. Delays to the exit and/or approach were shown, as appropriate, for each tow of the 40-tow queue and these times were totaled by chamber to compute the percent utilization resulting from this limited application of selective tow sequencing policies and schedules.

Components of the Lockage Procedure Used in the Analysis

134. In order to accurately chart the physical operations taking place in both chambers, a relatively detailed breakdown of the components of the lockage procedure was made for each lockage type, within the limitation of the times available through PMS. The lockage types consisted of straight singles, doubles and triples, and single setovers and knockouts. Average times were determined for the lockage components tabulated below:

Type of Lockage	Components of the Lockage Process
Single	Approach, entry, chambering, exit
Double	Approach, $entry_1$ (includes break and backout of first cut) $chambering_1$, $exit_1$, lock turnback (or swing-around), $approach_2$, $entry_2$, $chambering_2$, $exit_2$ (includes recoupling of powered and unpowered cuts)
Triple	Approach, $entry_1$ (includes break and backout of first cut), $chambering_1$,

Type of Lockage	Components of the Lockage Process
Triple (Continued)	$exit_1$, lock $turnback_1$, $approach_2$, $entry_2$, $chambering_2$, $exit_2$, lock $turnback_2$, $approach_3$, $entry_3$, $chambering_3$, $exit_3$ (includes recoupling of powered and unpowered cuts)
Setover or Knockout	Approach, entry (includes break and maneuver to a setover or knockout configuration), exit (includes remake to river travel configuration)

The average processing time for each component listed above was based on 5 months of PMS data to account for the effect of seasonality, if any (see Tables 39 and 40). The times for each lockage component were placed on a bar graph, to scale, with upper approach blockage indicated by a solid line and lower approach by a dashed line, as shown in Figure 30. The bar graphs were then cut into individual strips for use in charting the lockage of all tows in a selected sequence on a long sheet of graph paper. The procedure for doing this will be discussed in further detail later.

Random Selection of a Tow Queue

135. A fictitious list of tows was randomly selected from an available TOWGEN printout. Since many of the tows presently using Gallipolis are configured for lockage through the larger locks on the Ohio River, it was assumed that the tow characteristics in the year 1984 would be about the same as for today. A queue length of 40 tows was considered to be the maximum practical number for hand selection and graphical processing and a minimum for the computation of utilization levels for both chambers operating under this policy. The tow list used in the test analysis is shown in Table 41. Arrival order (column 1 of Table 41) is simply based on arrival time, with the earliest arriving tow as number one and progressing chronologically to tow number forty. The tow numbers in column 2 were taken directly from the TOWGEN printout and are listed on the table for future identification within a complete TOWGEN listing, which includes several hundred tows. The arrival times

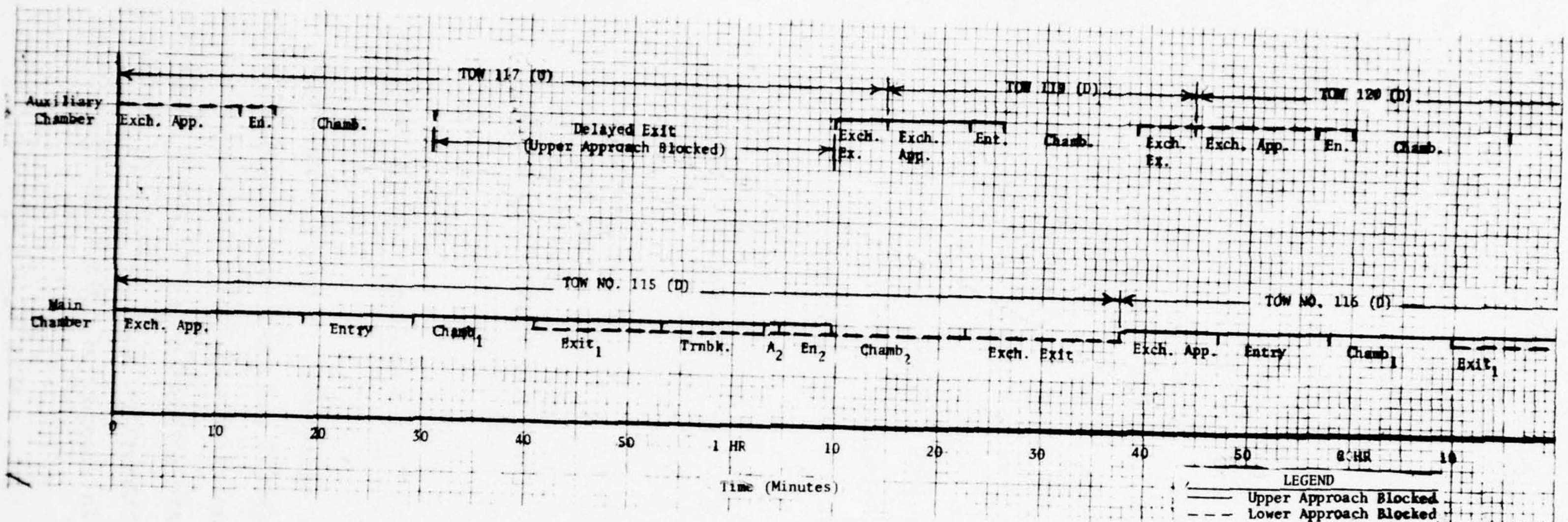


Figure 30. Example of graphical tow scheduling technique

in column 3 were taken from the TOWGEN list to show the relative frequency of the tow interarrival times (time between arrival of each successive tow). The direction of travel, tow length, tow width, number of barges, and barge type were readily available either from the 1984 TOWGEN printout or a WATSIM run, for which infinite queuing occurred for the 1984 traffic. The WATSIM program prints tows and additional tow characteristics over and above those shown on the TOWGEN printout whenever infinite queuing occurs. The lockage types in columns 9 and 10 were obtained from Table 1 on the basis of chamber selected, tow size, and barge type. At the time the lockage types were assigned, no determination had been made as to which chamber a certain tow would use. However, the natural procedure would be to lock the smaller tows through the auxiliary chamber first so as to minimize interference with the entry and exit of tows to and from the main chamber. Information in columns 11 and 12 was obtained from the bar chart after all tows had been graphically processed.

136. An analysis of the 40 randomly selected tows revealed the following:

a. Twenty-five tows would have to be broken into three or more cuts for lockage in the auxiliary chamber. The main chamber would normally be more suitable for lockage of these larger tows.

b. Fifteen tows could be processed by the auxiliary chamber as multitow lockages (more than one tow in the chamber at one time), singles, doubles, or single knockouts, thus establishing the initial selection of tows to use the auxiliary chamber.

Analytical Procedures and Assumptions

137. A roll of continuous 10 by 10 graph paper, with the abscissa scaled to 1 in. equals 10 min, was used to graph the processes that would take place simultaneously in both chambers. Activities in the auxiliary chamber were graphed directly above those occurring simultaneously in the main chamber so that periods of channel blockage were clearly depicted. An example of this technique is shown in Figure 30

for several of the initial tows. Whenever a chamber became available, the next tow was considered for call-up on the basis of lockage type, arrival time, and direction of travel. As shown in Table 41, the lockage type of a particular tow usually differs, depending on the selected chamber. Tows were considered for lockage in their order of arrival, but the overriding consideration for call-up was based on maximizing the utilization of the facilities. As a result, there were occasions when it was more desirable to call a particular tow long ahead of another that had arrived earlier in order to preclude a period of lock idle time.

138. The general rules used to select tows for servicing were:

a. Interference with operations in the main chamber were kept to a minimum.

b. The auxiliary chamber was used to lock the waiting tows that were configured and sized as singles, doubles, single and double setovers, and single and double knockouts in that chamber. Triple lockages or more were not locked in the auxiliary chamber until lockage of the above types of tows had been completed and time was available for processing triples in the auxiliary chamber without unreasonably delaying operations in the main chamber.

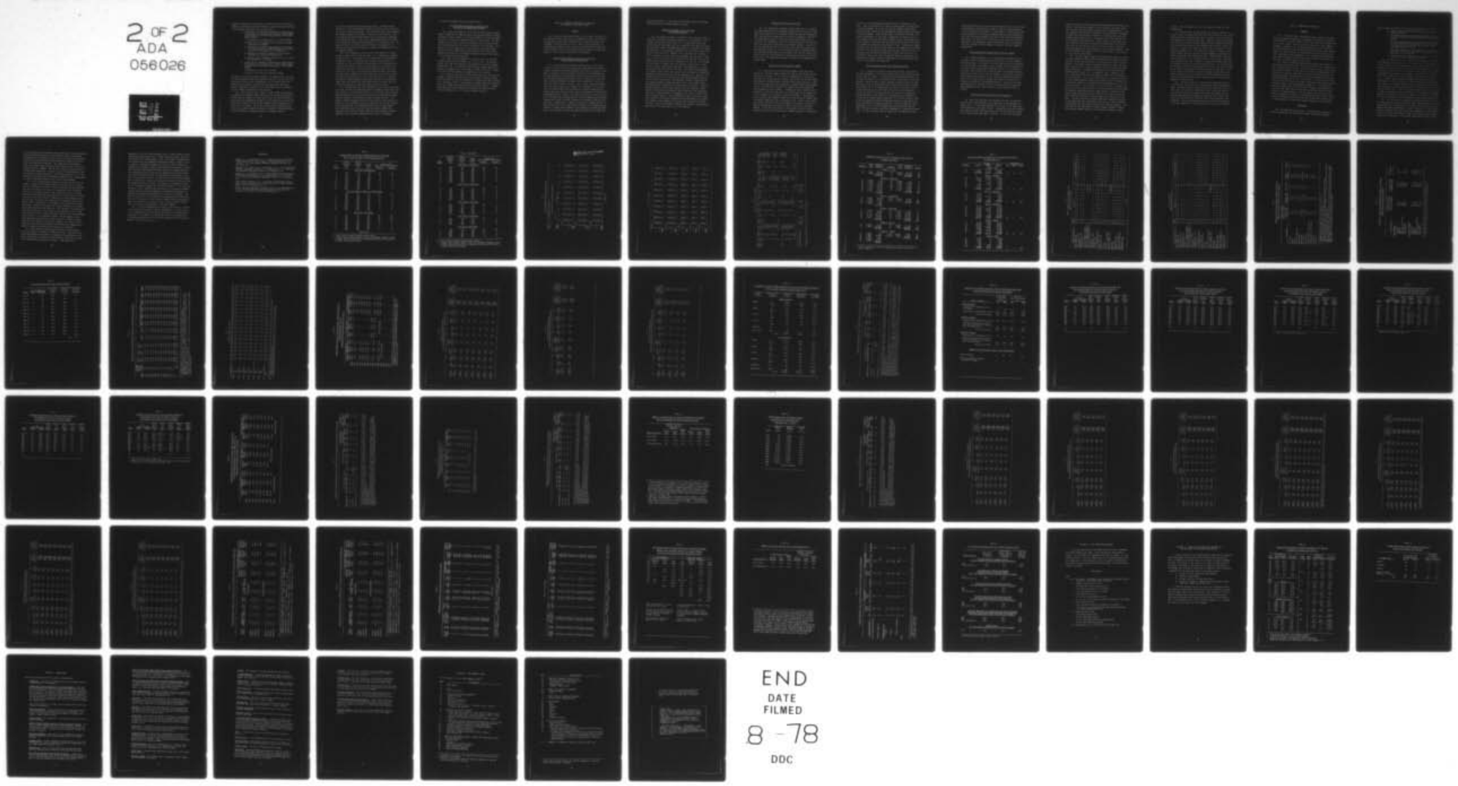
The first rule above was tantamount to the continuous, uninterrupted call-up of tows for use of the main chamber with little or no interruption, while the smaller candidates for the auxiliary chamber were called at times when operations in the main chamber were not blocking the entrance channel. Likewise, tows using the auxiliary chamber were, as a rule, allowed to exit only when the channel was not blocked. This continuous operation of the main chamber tended to maximize tonnage throughput. After the auxiliary chamber had completed locking all singles, doubles, etc., that were in the 40-tow queue, the call-up of triples did result in some delays to tows using the main chamber. However, this policy did eliminate a long period during which the auxiliary chamber would have been idle and was considered to be an acceptable tradeoff for improving utilization of the facility as a whole.

139. Certain assumptions had to be made concerning the practical aspects of some lock operations. The following physical operating

AD-A056 026 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 13/2
CAPACITY STUDIES OF GALLIPOLIS LOCKS, OHIO RIVER, WEST VIRGINIA--ETC(U)
MAY 78 L L DAGGETT , R W MCCARLEY

UNCLASSIFIED WES-TR-H-78-6 NL

2 OF 2
ADA
056026



END
DATE
FILMED
8-78
DDC

conditions would have to be possible in order to utilize the auxiliary chamber at the same time the main chamber is being used and for the subject scheduling techniques to be of any benefit:

a. A whole tow or a powered or unpowered cut thereof moored to the guide wall or guard wall of either chamber would not interfere with the following operations in the adjacent chamber:

(1) Extraction of an unpowered cut of a double lockage

(2) Short entry of a powered cut of a multicut lockage following lock turnback

(3) Breaking of the powered and unpowered cuts of multicut lockage within the chamber immediately following tow entry and backing out of the powered cut

(4) Remaking of a multicut lockage tow at the chamber following the lock processing operation

(5) Turnback (short) approach and entry of a tow, such as the powered cut of a double

b. A whole tow or a powered or unpowered cut thereof moored to the guide wall or guard wall of either chamber would interfere with the following operations in the adjacent chamber:

(1) Approach of a tow to be serviced

(2) Exit of a tow that has completed lockage

The above rules mean that channel blockage is assumed to deny tows only the powered approach toward and departure from the vicinity of the lock. Operations such as pulling out unpowered cuts, tow short entry, tow breaking and recoupling, and other such operations that take place within or immediately adjacent to the lock chamber would be performed in both chambers simultaneously when required.

140. As mentioned earlier, cutouts or paper strips were prepared to represent the component times involved in the locking process and the periods when the channels on either side of the lock would be blocked. These strips were prepared by chamber for each lockage type and for both directions of travel and used on the elongated sheet of graph paper to select tows for lockage. One or more cutout strips pertaining to particular tows could be placed on the chart, adjacent to the plotted bars of tows that had just completed lockage, to determine whether

significant interference and delays would result. Different cutout strips were tried and manipulated by hand to establish the best possible tow or tows for the next lockage. This process was quite time-consuming and somewhat complex to do by hand. The order of tow selection using this graphical procedure would probably vary to some extent, depending on the person who did it. Thus such a scheduling procedure would have to be refined and retested before employing it at a prototype lock. The purpose in using it for this study was solely to approximate the increased lock utilization that might be attained by scheduling the use of the approach channel.

141. First attempts at using this bar chart graphical technique involved a choice of entry and exit types, i.e., turnback and exchange, for waiting tows. This proved to be too complex and time-consuming to accomplish by hand. To determine the entrance and exit types of a candidate tow, the exit type of the previous tow and the entrance type of the next tow had to be known for both chambers. In addition, consideration would have to be given to the channel blockage that would continue to exist until a tow reached the approach point, even though it had executed a turnback exit that allows the lock to start its turnback when the departing tow's stern crosses the lock sill. Likewise, tows making turnback approaches would block entrances to the adjacent chamber not only during their short approach but also while they traveled to the guide wall or guard wall and waited for call-up.

142. Although some time could possibly be saved, especially during high water periods by scheduling the tows for turnback entries and exits when possible, in reality there would be very few such entries and exits made during periods of high utilization in both the main and auxiliary chambers because of the additional channel blockage involved. Tows making a turnback approach would have to be moored on the guide wall or guard wall in the proximity of the lock gates and wait for the lockage of the preceding tow to be completed and the lock to swing around. This would block entry to and exit from the adjacent chamber for a longer period of time and further complicate the scheduling procedure. Therefore lock utilization computations were based on scheduling

all tows for exchange entries and exchange exits.

Lock Utilization and Capacity Resulting from the Use of Tow Scheduling Procedures

143. After the lockage of all 40 tows had been plotted on graph paper, a tabulation of required delays resulting from channel blockage was made as shown in Table 42. The tows affected are listed by chamber along with the time their approach and/or exit was delayed. The main chamber was utilized to lock 20 tows during a 38-hr, 45.5-min period while experiencing only 216.8 min of delays due to interference. This equated to a 90.7 percent level of utilization in the main chamber. Use of the lock by light boats and recreational craft, which could probably enter and exit even though the channel was partially blocked, is not included in this percentage.

144. The auxiliary chamber also serviced 20 tows but finished slightly ahead of the main chamber at 37 hr, 5.5 min. The expected greater delay due to interference from operations in the main chamber totaled 560.5 min. Utilization of the auxiliary chamber during this period was computed to be 74.8 percent, as shown in Table 42. Average utilization of both chambers was computed to be 82.8 percent.

145. Based on the results of this limited analysis, the auxiliary chamber at Gallipolis possibly could be utilized to a greater extent than anticipated if tows were selected for lockage on the basis of their size, direction of travel, and availability during times when operations in the main chamber were not blocking the approach channels. Tonnage levels and delays corresponding to 83 percent lock utilization were obtained from Figures 4, 5, 7, and 8 as shown in Table 43.

PART IX: SUGGESTED OTHER MEANS OF INCREASING THE CAPACITY OF GALLIPOLIS LOCKS

General

146. There are other potential means of increasing the capacity of the Gallipolis Locks; some involve the adoption of other types of operating policies, while others consider minor, relatively low cost, improvements to the existing facilities. Most of the suggestions for increasing the capacity of the locks and for delaying costly major construction appear to hold little promise but were studied so that their benefits, if any, could be considered and documented.

Requirement for Adequate Clearance of the Locks' Water Intake and Outlet Areas

147. A rule would be established requiring tows to stay sufficiently clear of lock filling and emptying system intakes and outlets so that the chamber filling and emptying time could be reduced to a minimum. Discussions with the lockmen at Gallipolis and the Operations Division personnel at the Huntington District office revealed that the lock filling and emptying system must often be operated at rates somewhat less than the design rates when a tow or portion of a tow is located near these intakes or outlets. This is done to prevent damage to tows due to the suction of the intake or the turbulence in the outlet area. One would assume that the amount of increased chambering time required when this condition exists could be determined by observing PMS chambering times for single cut lockages when the exit of the tow was a fly or exchange type and comparing this with the chambering and turnback (between cuts) times for double lockages or the turnback time for lockages with a turnback entry. However, an analysis of sample PMS data indicated that there was no significant difference in the chambering times involved. Perhaps other parameters that influence the chambering times have a greater impact than the aforementioned reduction in filling and

emptying operations. In any event, the increased capacity from implementation of this rule would probably be small.

Consecutive Lockage of Tows Traveling in the Same Direction

148. The locking procedure at Gallipolis could require a series of consecutive lockages in the same direction, e.g., 6 Up-6 Down, 12 Up-12 Down, 12 Hours Up-12 Hours Down, etc. As indicated earlier, the 3 Up-3 Down and 4 Up-4 Down rules were simulated in the model for existing conditions and for switchboat operations at the lock and were found not beneficial. The so-called N Up-M Down rule is effective only if the sum of average times for a turnback exit, a turnback, and a turnback entry is much less than the time for an exchange exit and entry. When this is the case, the lock may be reversed, and a new tow can enter the chamber faster than two tows can exchange use of the lock. Even though this may result in slightly more efficient use of the lock, it often causes increased average delay times and is only beneficial if a queue is present at the locks most of the time. The effects of implementing any desired version of this rule could easily be simulated in WATSIM by changing the operational option for the simulated lock. However, calculations based on the July 1975 PMS data for the main chamber indicate that no benefit would result from sequential turnback lockages because the turnback operation would take from 4.5 to 9.3 min longer than an exchange operation, depending on the direction of tow travel. However, during high water periods, lock turnback times are sometimes shorter because of the smaller difference in water elevation, thus indicating there may be some advantage to implementing this rule at certain times when the queues build up. Strict adherence to the rule may not be possible because of the greater interference with operations in the auxiliary chamber as tows approach for long periods of time from a single direction. Because of the many variables, the lockmaster should decide when and how the N Up-M Down rule is to be applied.

Schedule Tow Arrivals at the Lock

149. This operational procedure could be beneficial if a significant time differential exists between exchange tow entry and exit times when the entering tow is not required to stop and when the entering tow must stop and then overcome inertia to begin its approach to the lock. It is anticipated that the resulting time savings and hence the increased traffic throughput is not very significant due to the difficult entry into the locks, particularly in the upper approach. Analysis of the July 1975 PMS data does not indicate that such time savings exist. Any reduction in delay at the lock resulting from the implementation of this procedure would probably be misleading since the tows would be delayed in route by being required to slow down or stop prior to arriving at the lock. This operational change is therefore not recommended for further study.

Greater Use of the Auxiliary Chamber

150. Increased use of the auxiliary chamber should come about naturally as the main chamber becomes more heavily utilized and the delays to tows increase. It will then be advantageous for smaller tows to double lock in the auxiliary chamber, rather than wait for the larger main chamber. WATSIM presently simulates these actions directly in that each tow arriving at the lock and waiting in queue decides which chamber to use. This decision is based on the earliest estimated completion time determined for each chamber. A chamber may have a "penalty time" assigned to it for particular types of lockages that may discourage the use of a chamber, e.g., double or triple cut lockages. This penalty time is added to the computed lockage time estimate and the chamber with the earliest completion time is selected for use. Thus, as the waiting time becomes excessive for the main chamber, the penalty time will become less significant, and tows will begin to utilize the auxiliary chamber. As was discussed earlier in this report, there are severe limitations on the use of the auxiliary chamber because of its location

adjacent to the main chamber and because of river conditions at the site. Table 16 revealed that as long as numerous double lockages occur in the main chamber, the use of the auxiliary chamber cannot exceed about 45 percent because of the interference created by these operations in the main chamber. Other lockage types, in addition to doubles, also create interferences as they enter, reconfigure, and depart, but to a lesser degree since only the double lockages require that unpowered cuts be left moored to the guide wall where they block entrance to the auxiliary chamber for relatively long periods of time. Elimination of double lockages, which now must break and remake in the chamber, could increase utilization of the auxiliary chamber to about the 76-percent level. As discussed, the FIFO Ready-to-Serve policy, which requires the use of switchboats, would insure that all doubles locked as singles; but its adoption would require structural improvements to provide mooring facilities for reassembling the large tows.

Maintain Optimum Depths in the Approach Channels

151. A suggestion was made to keep the approaches, particularly the lower approach, at a depth that would allow the most efficient entry of tows into the chambers. A rather serious shoaling problem exists in the approach channels to the Gallipolis Locks, particularly in the lower approach. There has been no major dredging of these channels for many years because of the interference such operations have with the traffic passing the locks. The reduced depth has thus had a hydraulic effect on tows entering the lock and tends to slow the vessel's approach. An analysis of entry time savings that may be realized by dredging the channel approaches could possibly be estimated from past research on the effects of reduced channel dimensions on tow transit times or could be done by comparing observed PMS approach and entry times before and after completion of a dredging operation. Analysis of PMS data taken immediately after the minor dredging operations performed from 6-12 April 1976 did not reveal significant improvements in approach and entry times. If time reductions could be quantified, the impact that such

time savings would have on the utilization efficiency of the locks could be determined by simulating the lockages, using the reduced approach times as input data to the model. In some cases, a submerged wing dike has proved useful in reducing or stopping shoaling in lock approaches. Such a solution would eliminate lost time at the locks during dredging operations. The increase in lock capacity solely from this option is considered to be negligible; however some benefit could be recognized from this, together with the adoption of some of the other suggested improvements.

Tow Reassembling for Maximum Use of the Lock Chamber

152. Another suggestion is to encourage the reassembling of waiting tows so that each vessel makes the fullest use of a lock chamber with each lockage. For example, some time could be saved at Gallipolis if tows requiring a knockout or setover lockage could be configured for a straight single lockage before entering the lock. An extension to this rule could require tows to break out barges and combine them with other tows in order to fill the lock chamber. To obtain any measurable benefit from this procedure, tows of the proper configuration must be present at the same time with enough time available to them prior to lockage to perform the reassembling necessary. Factors such as legal responsibility and insurance liability for the vessels and cargo may make implementing such a plan difficult, and the benefits would be limited.

High Versus Low Water Conditions at Gallipolis

153. High flow conditions are considered to exist at Gallipolis when the total vertical height of all open gates at the dam equals or exceeds 25 ft. At total gate openings of less than 25 ft, normal operating conditions are assumed to exist. Long periods of records indicate that generally normal conditions prevail at the locks about 65 percent of the time and high flows about 35 percent. As river flow increases,

adverse currents in both the upper and lower approaches become more pronounced. An additional lockman is often required on the upper guide wall to handle tow checklines during the entry of downbound tows. During extremely adverse current conditions, two lockmen must be assigned to handle the head checkline to offset the strong outdraft that pulls downbound tows toward the dam. Conditions in the lower approach are also hazardous during high flows. Further details on how adverse current conditions are created at Gallipolis and how they affect the approach and exit of tows are given in a section of PART VI entitled "Hazardous Approach and Exit Conditions at the Auxiliary Chamber." Many of the statements made earlier in this section of PART VI also pertain to tows using the main chamber.

154. The above remarks suggest that perhaps the locks can be operated more efficiently during normal flow periods than during periods of high flow because one would expect tow entry and exit times to be much greater. On the other hand, the reduced difference in upper and lower pool elevations tends to reduce chambering and lock swing-around times during high flows. To compare the differences in low and high water lockage component times (i.e., tow approach, entry, chambering, and exit), pertinent PMS data for the months of October 1975 and February 1976 were analyzed. The results of this analysis are shown in Table 44. Fly and exchange approaches during the high flow month of February were a few minutes longer in each chamber but turnback approaches were comparatively shorter. Thus, contrary to current beliefs, it appears that there was not very much difference in the recorded high water and normal flow approach times during the two sample periods. Perhaps the additional lockmen handling checklines enable tows to enter in about the same time during high flows as during normal flows without the checklines. The data in Table 44 indicate substantial reduction in double lockage chambering times during high flows, but only small differences in chambering times for singles and setover or knockout lockages. Time reductions are more noticable for double lockages, probably because three separate chamber operations are required to complete a double

lockage. Thus the reduced lift will allow greater savings for this lockage type.

155. The results of the high versus low water data analysis, as given in Table 44, suggest that more tows can be locked per unit of time during high flows than during low water, especially in view of substantial reductions in double lockage times. However, experience has shown that utilization of the auxiliary chamber decreases dramatically during high water periods because of the aforementioned hazardous current conditions. At certain very high water flows, tows are unable to use the auxiliary chamber at all. This reduction in auxiliary chamber utilization should offset any increase in lock throughput recognized by the reduced chambering times during high water. Unfortunately, there are too many variables (e.g., horsepower, flotilla size, pilot experience, load, commodity type, etc.) involved to accurately determine the limits of auxiliary chamber utilization during high flows. It would therefore be impossible to predict how many tows would utilize the auxiliary chamber as future queue lengths build during periods of high water. This being a primary constraint on increased lockage capacity during high water, the capacity of the Gallipolis Locks was determined only for the prevailing normal flow periods, when utilization of the auxiliary chamber is better defined.

156. The data in Table 44 indicate that an operating policy of N Up-M Down may be beneficial in reducing queue lengths during high flows. Turnback times are apparently reduced to the extent that a tow could exit, the lock could swing around, and a waiting tow enter in less combined time than it would take to make an exchange exit and exchange approach by the departing and entering tows, respectively. Use of the N Up-M Down rule should be left to the discretion of the lockmaster, since the following tows waiting on the lock guide walls of the main chamber will limit utilization of the auxiliary chamber.

PART X: SUMMARY AND CONCLUSIONS

Comments

157. The present delays experienced by tows using the Gallipolis Locks are apparently acceptable to industry, with certain reservations, and therefore the economic capacity of the lock from their viewpoint has not yet been reached. However, projected increases in bulk commodity shipments, especially coal and petroleum products, on this portion of the inland waterway system, suggest that both the physical and economic capacity of these locks may be surpassed before the inevitable structural improvements can be completed. This investigation has addressed the subject of physical capacity but does not attempt to quantify the more elusive economic capacity of the locks.

158. Official recorded tonnages passing through the Gallipolis Locks during 1969 and 1976 were 26.8 and 36.9 million tons, respectively, for an average annual increase of over 5 percent per year. Based on the best economic analysis to date, the total traffic through Gallipolis is expected to increase an additional 17.8 million tons by 1981, thus imposing increasingly exorbitant delays on the tows approaching the lock. The towing industry may by 1981, if not before, be forced to limit operations on this portion of the waterway, thereby forcing shippers to seek alternative modes of transporting bulk commodities. Given the lower waterway shipping rates, the end result of shipping large quantities by rail and truck rather than by water would be greater costs of the end products at consumer markets. This investigation was therefore initiated to determine the capacity of the existing Gallipolis Locks, considering both operational and minor structural changes that could be used as interim measures to improve the locking efficiency of this facility.

Conclusions

159. The sponsoring organization, in cooperation with engineers at WES, decided that the investigation should include the following

major alternative measures for increasing the capacity of the locks:

a. Selected operating policies for the existing Gallipolis lockage facilities

b. Switchboat operations in the upper pool where mooring facilities would be required for remaking tows following lockage

c. Switchboat operations in the upper pool, as in b above, plus an extended landward guide wall in the lower pool to be used by tows to recouple after lockage without delaying turnback of the lock

d. Switchboat operations in the upper pool, as in b above, plus either switchboat operations or an extended center guard wall in the lower pool

e. FIFO Ready-to-Serve operating policy, which also would require switchboats and mooring facilities

160. The above-listed alternatives were investigated using simulation modeling techniques, as discussed in the body of this report, and the results are briefly summarized in Table 45 for comparison. The alternatives shown in Table 45 are arranged in the order of increasing lock capacity, with the year the projected tonnage level should exceed the computed lock capacity also included. As expected, the Ready-to-Serve policy, wherein all multicut lockage tows are locked as singles (e.g., a double lockage becomes two singles with the assistance of a switchboat), was the most effective in terms of physical tonnage capacity. However, total annual delay is higher because of the increased lock utilization as more and more tows are introduced into the waterway system in future years. This is also true for the other policies listed in Table 45, thus portraying the importance of determining the economic capacity in addition to the physical capacity. At this time the delays that can be tolerated by the towing industry have not been quantified.

161. All of the policies simulated, with the exception of the one involving only the existing facilities, would require certain structural improvements such as mooring cells, extended wall, and perhaps certain proposed ancillary appurtenances, as shown in Figure 26. These improvements are considered relatively minor when compared to the replacement of the entire lock, and attempt to reduce the present adverse locking conditions at Gallipolis. The extended lower guide wall was proposed

as an alternative to the extended center guard wall so that interference with lock operations during its construction could be circumvented. Construction of a landward guide wall would not disrupt lock operations as much, but approach channel blockage would occur while tows used it after construction was completed. Tows remaking on, and otherwise using, an extended center guard wall would not block entry to and exit from the auxiliary chamber. Thus the lock capacity associated with an extended center guard wall is slightly greater than that shown for the extended lower landward guide wall. Switchboat operations in the lower pool would yield about the same tonnage throughput as the extended guard wall but tow maneuvers would be more difficult and hazardous.

162. The N Up-M Down operating policy proved to be the least desirable in terms of both tonnage capacity and delays for all alternatives, as indicated in Table 45. Several simulation runs were made for this policy to analyze its benefits for immediate use at the present facilities. The model indicated that delays would actually increase under the N Up-M Down policy during periods of normal river flow (about 65 percent of the time) because a departing tow could exchange use of the lock with an entering tow traveling in the opposite direction more rapidly than a turnback exit, lock turnback, and turnback entry could take place. During certain high water periods, there may be an advantage to employing the N Up-M Down rule. The difference in the upper and lower pool elevations is not as great during high water, thus at some point allowing the lock to turn back faster than two tows could exchange use of the lock. It is doubtful, however, that the capacity of the locks increases during high flows since the adverse currents created reduce the utilization of the auxiliary chamber. The extent of this reduction varies with many parameters and therefore the computation of capacity associated with high flow periods was not possible.

163. Other means of increasing the capacity of the Gallipolis Locks were studied as reported in PARTS VIII and IX. Some of the suggested improvements show promise for improving locking conditions, and others would really not make very much difference, especially in view of the anticipated rapid growth in traffic. Requiring tows to

adequately clear the intake and outlet areas to reduce chamber filling and emptying times would result in longer turnback entries, thus nullifying some of the savings gained. Such a rule could be implemented at the discretion of the lockmaster during periods when a savings in time is apparent. Maintenance dredging to reduce the adverse effects of shoaling in the entrance channel should speed up the approach of vessels for a while but would block the channel during the dredging operation. The scheduling of tow arrivals was not judged to be practical because tows would be delayed in route by being required to slow down or stop prior to arriving at the lock. Of course, use of the auxiliary chamber must be increased in order to get the desired levels of utilization from the lockage facility as a whole. The benefits of scheduling tows for use of the approach channels were analyzed in PART VIII. This analysis, limited as it was, indicated that utilization of the auxiliary chamber probably could be increased through use of scheduling techniques, although such techniques would probably be difficult to implement. The physical capacity of the existing locks could approach 50 million tons per year if utilization of the auxiliary chamber could be increased to about the 75-percent level shown in Tables 42 and 45 without substantially interfering with operations in the main chamber.

164. No final recommendations are made in this report as to which of the possible alternatives should be implemented. In order to make such a recommendation, factors beyond the scope of this report must be considered. The economic cost and benefits for each alternative and the engineering feasibility of the analyzed approaches are being determined by the Huntington District.

REFERENCES

1. Daggett, L. L. and McCarley, R. W., "Capacity Studies of Winfield Locks, Kanawha River, West Virginia," Miscellaneous Paper H-77-1, Feb 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

2. Daggett, L. L., Ankeny, T. D., and Eiland, J. A., "A New Generalized Waterways Simulator: Watsim IV" (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

3. Daggett, L. L. and Ankeny, T. D., "Determination of Lock Capacities Using Simulation Modeling," Miscellaneous Paper H-75-9, Dec 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

4. Peat, Marwick, Mitchell & Co., "Evaluation of Operational Improvements at Locks and Dam No. 26, Mississippi River," Draft of Final Report, Apr 1975, Washington, D. C.

5. Office, Chief of Engineers, Department of the Army, "Implementation of the Performance Monitoring System; Reports and Statistics," Circular No. 335-2-18, 2 Jan 1975, Washington, D. C.

Table 1

Lockage Types by Tow Size and Barge Type at the Existing
600 × 110 ft and 360 × 110 ft Gallipolis Locks

No. Barges	Total* Flotilla Length ft	Total Flotilla Width ft	Pusher Length ft	Lockage Type** 600 × 110 ft Chamber	Lockage Type** 360 × 110 ft Chamber
		Tows with R BULK Barges			
2	240	52	65	55	55
4	415	52	65	55	44
6	415	78	65	1	2
8	450	104	100	1	2
9	625	78	100	44	2
12	630	104	105	2	2
15	810	104	110	2	3
16	825	104	125	2	3
18	1030	104	155	2	3
20	1030	104	155	2	3
		Tows with JUMBO (J BULK or J TANK) Barges			
1	260	35	65	55	55
3	260	105	65	55	1
5	455	105	65	1	2
6	475	105	85	1	2
8	685	105	100	44	3
9	685	105	100	2	3
12	930	105	150	2	4
14	1125	105	150	2	5
15	1125	105	150	2	5
16	1170	105	150	2	6
		Tows with I 150 Barges			
1	215	52	65	55	55
2	385	52	85	55	44
3	570	52	120	55	44
4	730	52	130	44	2
5	580	104	130	1	2
6	580	104	150	1	2
7	750	104	150	2	3
8	750	104	150	2	3
9	900	104	150	2	3

(Continued)

* Total flotilla length includes pusher length.

** Lockage types indicate number of cuts for standard lockages, except 55 which indicates multiple tow lockages are possible and 44 which is a single setover-type lockage.

Table 1 (Concluded)

No. Barges	Total* Flotilla Length ft	Total Flotilla Width ft	Pusher Length ft	Lockage Type** 600 × 110 ft Chamber	Lockage Type** 360 × 110 ft Chamber
		Tows with IP 200 Barges			
1	290	52	90	55	55
3	700	52	110	44	2
4	920	52	120	44	3
5	730	104	130	2	3
6	750	104	150	2	3
7	950	104	150	2	4
8	950	104	150	2	4
9	1150	104	150	2	5
10	1150	104	150	2	5
		Tows with IC 200 Barges			
2				1	44
3	700	52	110	44	2
4	920	52	120	44	3
5	730	104	130	2	3
6	750	104	150	2	3
7	950	104	150	2	4
8	950	104	150	2	4
10	1150	104	150	2	5
		Tows with IP 250 Barges			
3	860	54	110	44	3
4	1150	54	150	2	4
5	900	108	150	2	4
6	900	108	150	2	4
7	1150	108	150	2	5
8	1150	108	150	2	5
		Tows with IC 250 Barges			
3	860	54	110	44	3
4	1150	54	150	2	4
6	900	108	150	2	4
7	1150	108	150	2	5
		Tows with I 300 Barges			
1	410	54	110	55	44
2	720	54	120	44	2
3	1050	54	150	44	3
5	1050	108	150	2	4
6	1050	108	150	2	4

* Total flotilla length includes pusher length.

** Lockage types indicate number of cuts for standard lockages, except 55 which indicates multiple tow lockages are possible and 44 which is a single setover-type lockage.

110

Table 2

Tow Size/Horsepower Distribution by Tow Type

UTILITY 1 *** GALLIPOLIS STUDY 1975 TRAFFIC

FREQUENCY DISTRIBUTION OF EXPECTED TOW CHARACTERISTICS

REACH 1

NO. OF BARGES PER TOW	TOWBOAT HORSEPOWER 750	1250	1750	2500	2750	3250	3750	4500	5000	0	TOTAL
TOW TYPE 1											
2	8.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0
4	13.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0
6	6.0	3.0	3.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0	15.0
8	1.0	3.0	3.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	11.0
9	1.0	3.0	1.0	3.0	1.0	0.0	0.0	0.0	0.0	0.0	9.0
12	1.0	5.0	1.0	3.0	2.0	0.0	1.0	1.0	0.0	0.0	14.0
15	0.0	0.0	0.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0	4.0
16	0.0	0.0	1.0	0.0	4.0	2.0	1.0	1.0	0.0	0.0	9.0
18	0.0	0.0	0.0	1.0	1.0	1.0	4.0	0.0	0.0	0.0	7.0
20	0.0	0.0	0.0	0.0	2.0	1.0	2.0	2.0	0.0	0.0	7.0
TOTAL PERCENT	30.0	16.0	9.0	12.0	15.0	5.0	9.0	4.0	0.0	0.0	100.0
TOW TYPE 2											
1	1.0	2.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	4.0
3	5.0	4.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	10.0
5	6.0	2.0	2.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	12.0
6	1.0	0.0	3.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0	7.0
8	2.0	0.0	4.0	0.0	2.0	0.0	4.0	0.0	0.0	0.0	12.0
9	1.0	6.0	0.0	0.0	1.0	3.0	0.0	0.0	0.0	0.0	11.0
12	1.0	0.0	0.0	0.0	2.0	1.0	4.0	1.0	1.0	0.0	10.0
14	0.0	0.0	0.0	1.0	1.0	2.0	4.0	1.0	0.0	0.0	9.0
15	0.0	1.0	0.0	2.0	2.0	2.0	6.0	2.0	0.0	0.0	15.0
16	0.0	0.0	0.0	1.0	1.0	3.0	4.0	1.0	0.0	0.0	10.0
TOTAL PERCENT	17.0	15.0	9.0	4.0	12.0	12.0	25.0	5.0	1.0	0.0	100.0
TOW TYPE 3											
1	6.0	0.0	0.0	0.0	0.0	6.0	0.0	6.0	0.0	0.0	18.0
2	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0
3	0.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0
4	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0
5	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0
6	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0
7	0.0	6.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	12.0
8	0.0	0.0	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	13.0
9	0.0	6.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	12.0
TOTAL PERCENT	19.0	37.0	0.0	7.0	0.0	31.0	0.0	6.0	0.0	0.0	100.0

(Continued)

Table 2 (Concluded)

TOW TYPE 4

1	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0
3	0.0	11.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.0
4	0.0	0.0	4.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	8.0
5	0.0	4.0	7.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	18.0
6	5.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0
7	0.0	0.0	0.0	0.0	0.0	7.0	4.0	0.0	0.0	0.0	11.0
8	0.0	7.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	11.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0	0.0	0.0	11.0
10	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	7.0
TOTAL PERCENT	5.0	26.0	25.0	0.0	0.0	18.0	8.0	18.0	0.0	0.0	100.0

TOW TYPE 5

2	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	7.0
3	0.0	0.0	0.0	0.0	0.0	6.0	7.0	7.0	0.0	0.0	20.0
4	0.0	7.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0	19.0
5	0.0	0.0	0.0	0.0	0.0	6.0	6.0	0.0	0.0	0.0	12.0
6	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0
7	0.0	6.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	12.0
8	0.0	12.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	18.0
10	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0
TOTAL PERCENT	0.0	37.0	0.0	0.0	0.0	25.0	19.0	19.0	0.0	0.0	100.0

TOW TYPE 6

3	0.0	4.0	2.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	14.0
4	6.0	0.0	3.0	3.0	0.0	0.0	2.0	17.0	6.0	0.0	37.0
5	0.0	0.0	3.0	0.0	0.0	2.0	0.0	6.0	0.0	0.0	11.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	2.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	3.0
8	0.0	0.0	0.0	0.0	0.0	11.0	11.0	8.0	3.0	0.0	33.0
TOTAL PERCENT	6.0	4.0	8.0	3.0	8.0	13.0	13.0	36.0	9.0	0.0	100.0

TOW TYPE 7

3	0.0	0.0	0.0	0.0	0.0	18.0	0.0	0.0	0.0	0.0	18.0
4	0.0	10.0	9.0	0.0	0.0	18.0	0.0	18.0	0.0	0.0	55.0
6	0.0	0.0	0.0	0.0	0.0	0.0	9.0	9.0	0.0	0.0	18.0
7	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0	9.0
TOTAL PERCENT	0.0	10.0	9.0	0.0	0.0	36.0	18.0	27.0	0.0	0.0	100.0

TOW TYPE 8

1	0.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0	0.0	9.0
2	0.0	0.0	0.0	0.0	5.0	38.0	0.0	0.0	0.0	0.0	43.0
3	0.0	0.0	0.0	0.0	0.0	9.0	0.0	5.0	0.0	0.0	14.0
5	0.0	5.0	9.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	19.0
6	0.0	0.0	5.0	0.0	0.0	0.0	5.0	5.0	0.0	0.0	15.0
TOTAL PERCENT	0.0	5.0	14.0	0.0	5.0	56.0	10.0	10.0	0.0	0.0	100.0

Table 3

Gallipolis Locks and Dam Traffic Summary

Barge Type	No. Barges	Commodity*	Tons Cargo
R BULK	645	10	599,750
	1	31	800
	4	40	2,950
	2	41	1,600
	6	43	4,200
	8	50	6,800
	7	51	6,000
	56	52	46,200
	1	60	900
	1	62	900
	6	95	700
	6	99	4,200
	743		675,000
J BULK	811	10	1,204,450
	7	11	9,600
	35	40	39,000
	31	41	40,500
	78	42	109,300
	136	43	151,139
	14	44	20,800
	16	45	15,600
	2	46	2,600
	4	50	5,700

(Continued)

Barge Type	No. Barges	Commodity	Tons Cargo
J BULK (Cont.)	22	52	31,100
	2	53	3,000
	12	60	17,500
	5	62	10,000
	1	80	1,400
	4	88	5,700
	4	90	5,800
	3	95	1,100
	25	99	29,600
	1212		1,703,889
J TANK	4	20	5,600
	1	21	1,100
	10	22	16,500
	1	23	1,200
	11	24	15,400
	14	25	20,200
	10	26	12,450
	20	30	25,400
	23	31	26,700
	1	32	1,000
	2	38	3,800
	1	39	1,400
	98		130,750

Barge Type	No. Barges	Commodity	Tons Cargo
I 150	17	20	31,850
	15	30	27,300
	32		59,150
IP 200	17	20	33,341
	1	21	1,200
	34	22	60,559
	8	23	15,000
	6	24	13,000
	10	25	20,100
	10	26	18,244
	86		161,444
IC 200	53	30	106,100
	6	31	16,628
	3	32	5,000
	3	54	8,315
	65		132,043
IP 250	1	20	4,000
	10	21	30,000

(Continued)

Barge Type	No. Barges	Commodity	Tons Cargo
IP 250 (Cont.)	46	22	133,800
	8	23	26,400
	12	24	34,900
	32	25	91,440
	3	26	8,000
	112		328,540
IC 250	8	30	19,019
	18	31	53,825
	26		72,844
I 300	7	20	20,800
	12	22	30,300
	4	24	12,000
	5	35	11,600
	28		74,700
	GRAND TOTAL		3,338,360

AVERAGE LOAD PER BARGE, tons:

R BULK	950	I 150	1850	IP 250	2600
J BULK	1400	IP 200	1840	IC 250	2790
J TANK	1335	IC 200	2070	I 300	2670

* Commodity codes as specified in instructions for the PMS; see Appendix D.

Table 4

Commodity Group Analysis at Gallipolis Locks and Dam

December 1975 Data

Commodity	Barge Type	Tonnage by Commodity	Commodity	Barge Type	Tonnage by Commodity	Percent
		Group 1 - Coal				
10	R BULK	599,750	10	R BULK	599,750	33
10	J BULK	1,214,050	10	J BULK	1,214,050	67
		1,813,800			1,813,800	100
		Group 2 - Chemicals				
30	R BULK	800	30	R BULK	800	0
30	J TANK	58,300	30	J TANK	58,300	19
30	I 150	27,300	30	I 150	27,300	9
30	IC 200	123,728	30,54	IC 200	132,043	44
30	IC 250	72,844	30	IC 250	72,844	24
30	I 300	11,600	30	I 300	11,600	4
54	IC 200	8,315			302,887	100
		302,887				
		Group 3* - Aggregates				
50	R BULK	59,000	50,60	R BULK	59,900	51
50	J BULK	39,800	50,60	J BULK	57,300	49
60	R BULK	900			117,200	100
60	J BULK	17,500				
		117,200				
		Group 4 - Petroleum				
20	J TANK	72,450	20	J TANK	72,450	11
20	I 150	31,850	20	I 150	31,850	5
20	IP 200	161,444	20	IP 200	161,444	25
20	IP 250	328,540	20	IP 250	328,540	50
20	I 300	63,100	20	I 300	63,100	9
		657,384			657,384	100
		Group 5 - Metals				
40	R BULK	8,750	40	R BULK	8,750	2
40	J BULK	378,939	40	J BULK	378,939	98
		387,689			387,689	100
		Group 6 - Other				
62	R BULK	900	62,90	R BULK	5,800	10
62	J BULK	10,000	62,80,90	J BULK	53,600	90
80	J BULK	7,100			59,400	100
90	R BULK	4,900				
90	J BULK	36,500				
		59,500				

* Group 3 includes all 50 series commodities except 54 and all 60 series except 62.

Table 5

Directional Movement of Commodities at Gallipolis Locks and Dam

During December 1975

Commodity	Tonnage			Percentages		
	Up	Down	Total	Up	Down	Total
	Group 1 - Coal					
10	1,156,100	648,100	1,804,200			
11	9,600	0	9,600			
	1,165,700	648,100	1,813,800	64	36	100
	Group 2 - Chemicals					
30	143,419	35,600	179,019			
31	78,553	14,200	92,753			
32	6,000	0	6,000			
35	0	11,600	11,600			
38	1,400	2,400	3,800			
39	1,400	0	1,400			
54	8,315	0	8,315			
	239,087	63,800	302,887	79	21	100
	Group 3 - Aggregates					
50	12,500	0	12,500			
51	6,000	0	6,000			
52	48,100	29,200	77,300			
53	3,000	0	3,000			
60	17,000	1,400	18,400			
	86,600	30,600	117,200	74	26	100
	Group 4 - Petroleum					
20	95,591	0	95,591			
21	31,200	11,000	32,300			
22	212,559	28,600	241,159			
23	40,500	2,100	42,600			
24	75,300	0	75,300			
25	129,240	2,500	131,740			
26	35,794	2,900	38,694			
	620,184	37,200	657,384	94	6	100
	Group 5 - Metals					
40	14,450	27,500	41,950			
41	34,500	7,600	42,100			
42	106,300	3,000	109,300			
43	24,500	130,839	155,339			
44	19,500	1,300	20,800			
45	1,200	14,400	15,600			
46	2,600	0	2,600			
	203,050	184,639	387,689	52	48	100
	Group 6 - Other					
62	10,900	0	10,900			
80	1,400	0	1,400			
88	4,300	0	4,300			
90	5,700	0	5,700			
95	400	1,400	1,800			
99	31,600	3,700	35,300			
	54,300	5,100	59,400	91	9	100

Table 6

Frequency Distribution of Lock Component Times

Chamber 1 (October 1975 Data)

Component Description	WTD AVG	Time, min												Frequency of Occurrence, %											
Single Lockages, Up	17	10	12	13	14	15	16	17	18	20	23	24	27	3	7	3	13	17	17	10	7	7	10	3	3
Single Lockages, Down	14	7	8	10	11	12	13	14	15	16	17	19	24	2	5	3	8	10	24	10	20	8	6	2	2
Double & Double Knockout Lockages, Up	91	54	61	72	77	85	89	94	98	103	108	115	124	2	4	10	7	13	16	11	11	7	8	6	5
Double & Double Knockout Lockages, Down	73	48	56	59	64	68	71	77	80	84	88	94	108	4	8	8	16	5	14	13	8	7	8	4	5
Triple & Over Standard, Knockout, Setover, & Jackknife Lockages, Up		Not Applicable																							
Triple & Over Standard, Knockout, Setover, & Jackknife Lockages, Down		Not Applicable																							
Single Knockout & Setover Lockages, Up	41	19	25	27	29	31	34	38	41	47	59	64	74	2	10	10	9	8	3	12	9	12	12	8	5
Single Knockout & Setover Lockages, Down	30	13	18	21	24	26	29	31	35	40	53	64	0	4	14	5	14	14	18	5	9	4	4	9	0
Fly & Exchange Entries, Up	18	3	6	9	12	15	17	21	24	27	34	46	63	2	3	10	17	14	17	7	13	9	5	2	1
Fly & Exchange Entries, Down	18	3	7	9	12	16	18	21	24	29	35	40	55	2	6	13	17	17	12	9	8	7	4	3	2
Turnback Entries, Up	10	1	3	8	11	14	17	20	24	39	0	0	0	19	14	16	16	13	11	5	3	3	0	0	0
Turnback Entries, Down	12	1	2	4	6	9	12	15	19	22	32	37	48	19	11	11	8	8	11	11	3	6	3	6	3
Exit, Up	5	1	2	3	4	5	6	7	8	9	14	0	0	4	10	17	24	10	7	14	7	4	3	0	0
Exit, Down	6	2	3	4	5	6	7	8	10	11	15	0	0	12	16	10	14	11	3	16	9	7	2	0	0
Turnbacks (or Swing-arounds)	12	2	6	8	10	12	13	15	17	20	26	0	0	1	2	7	15	29	25	12	5	3	1	0	0
Open Pass Lockages, Short		Not Applicable																							
Open Pass Lockages, Long		Not Applicable																							
Break Times	10	1	3	8	11	14	17	20	24	39	0	0	0	19	14	16	16	13	11	5	3	3	0	0	0
Remake Times	12	1	2	4	6	9	12	15	19	22	32	37	48	19	11	11	8	8	11	11	3	6	3	6	3
Multiple Entry, Up	18	3	6	9	12	15	17	21	24	27	34	46	63	2	3	10	17	14	17	7	13	9	5	2	1
Multiple Entry, Down	18	3	7	9	12	16	18	21	24	29	35	40	55	2	6	13	17	17	12	9	8	7	4	3	2
Multiple Tow Lockages, Up	17	10	12	13	14	15	16	17	18	20	23	24	27	3	7	3	13	17	17	10	7	7	10	3	3
Multiple Tow Lockages, Down	14	7	8	10	11	12	13	14	15	16	17	19	24	2	5	3	8	10	24	10	20	8	6	2	2
Multiple Exits, Up	5	1	2	3	4	5	6	7	8	9	14	0	0	4	10	17	24	10	7	14	7	4	3	0	0
Multiple Exits, Down	6	2	3	4	5	6	7	8	10	11	15	0	0	12	16	10	14	11	3	16	9	7	2	0	0

(Continued)

Table 6 (Concluded)

Chamber 2 (October 1975 Data)

Component Description	WTD AVG	Time, min												Frequency of Occurrence, %											
Single Lockages, Up	17	12	13	15	16	17	18	19	20	21	0	0	0	5	5	16	5	26	11	11	11	10	0	0	0
Single Lockages, Down	16	9	12	13	14	15	16	17	18	19	20	22	24	3	6	8	14	19	8	17	8	8	3	3	3
Double & Double Knockout Lockages, Up	79	63	68	70	71	80	86	94	101	0	0	0	0	12	12	13	13	13	13	12	12	0	0	0	0
Double & Double Knockout Lockages, Down	70	58	61	62	64	69	73	77	85	91	0	0	0	9	8	8	17	17	17	8	8	8	0	0	0
Triple & Over Standard, Knockout, Setover, & Jackknife Lockages, Up	96	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0
Triple & Over Standard, Knockout, Setover, & Jackknife Lockages, Down	86	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0
Single Knockout & Setover Lockages, Up	32	11	19	23	25	26	28	29	32	37	42	50	69	3	11	9	14	6	9	8	3	17	6	11	3
Single Knockout & Setover Lockages, Down	35	17	22	26	29	32	34	38	48	53	54	58	77	7	23	15	8	7	4	8	12	4	4	4	4
Fly & Exchange Entries, Up	12	3	4	5	6	8	10	12	15	19	26	36	0	6	6	7	10	10	12	10	15	12	10	2	0
Fly & Exchange Entries, Down	10	1	2	3	5	7	9	11	12	16	20	25	42	5	8	11	15	15	8	10	5	8	5	5	5
Turnback Entries, Up	10	1	2	3	4	12	13	15	20	24	0	0	0	10	20	10	10	10	10	10	10	10	0	0	0
Turnback Entries, Down	8	1	2	3	4	6	10	12	13	17	20	0	0	9	8	8	17	17	8	8	8	8	9	0	0
Exit, Up	2	1	2	3	4	5	0	0	0	0	0	0	0	21	37	26	11	5	0	0	0	0	0	0	0
Exit, Down	2	1	2	3	4	5	6	0	0	0	0	0	0	21	46	20	8	3	2	0	0	0	0	0	0
Turnbacks (or Swing-arounds)	15	2	10	13	14	15	16	19	20	22	29	0	0	11	13	13	13	8	8	5	8	11	10	0	0
Open Pass Lockages, Short		Not Applicable																							
Open Pass Lockages, Long		Not Applicable																							
Break Times	10	1	2	3	4	12	13	15	20	24	0	0	0	10	20	10	10	10	10	10	10	10	0	0	0
Remake Times	8	1	2	3	4	6	10	12	13	17	20	0	0	9	8	8	17	17	8	8	8	8	9	0	0
Multiple Entry, Up	12	3	4	5	6	8	10	12	15	19	26	36	0	6	6	7	10	10	12	10	15	12	10	2	0
Multiple Entry, Down	10	1	2	3	5	7	9	11	12	16	20	25	42	5	8	11	15	15	8	10	5	8	5	5	5
Multiple Tow Lockages, Up	17	12	13	15	16	17	18	19	20	21	0	0	0	5	5	16	5	26	11	11	11	10	0	0	0
Multiple Tow Lockages, Down	16	9	12	13	14	15	16	17	18	19	20	22	24	3	6	8	14	19	8	17	8	8	3	3	3
Multiple Exits, Up	2	1	2	3	4	5	0	0	0	0	0	0	0	21	37	26	11	5	0	0	0	0	0	0	0
Multiple Exits, Down	2	1	2	3	4	5	6	0	0	0	0	0	0	21	46	20	8	3	2	0	0	0	0	0	0

Table 7

Gallipolis Locks and Dam Simulation Model Verification

Comparison of Total Results for Both Chambers

Description	Simulation Model Results (31 days*) December 1975 Input Data	Prototype Data December 1975	Differences %	4-Month Average**	Difference %
Total Tows	512	502†	+2.0	531	-3.6
Singles	26.8%	25.4%	+1.4	25.2%	+1.6
Doubles	52.6%	52.4%	+0.2	50.5%	+2.1
Setovers & Knockouts	20.6%	22.2%	-1.6	24.4%	-3.8
Loaded Barges	2438	2417	+0.9	2415	+0.9
Empty Barges	1658 (40.5%)	1788 (42.5%)	-2.0	1783 (42.5%)	-2.0
Utilization	44.8%	44.4%††	+0.4	46.5%	-1.7
Total Kilotons	3435	3381	+1.6	3226	+6.5
Average Delay of Tows Delayed	163	147	--	171	--
Average Delay of Tows Passing	110	147‡	--	144	--
Kilotons/Tow	6.71	6.74	--	6.09	--
Barges/Tow	8.00	8.38	--	7.9	--

* Adjusted from 30-day-month values provided by simulation run.

** October 1975 and January, April, and July 1976.

† Count excluded 13 Single Other Vessel lockages recorded in the auxiliary chamber.

†† Auxiliary chamber percent utilization adjusted downward by 0.6% to allow for exclusion of pleasure craft in the simulation model computations.

‡ PMS data for December 1975 indicates that all but 2 tows were delayed, including the fly entries. Since a number of tows recorded as being delayed were actually not delayed, the simulation model-computed delay of 110 min appears to be reasonably acceptable.

Table 8

Gallipolis Locks and Dam Simulation Model Verification

Comparison of Results by Chamber

Description	Simulation Model Results (31 days*) Dec 1975 Input	Prototype Data December 1975	Difference %
Main Chamber			
Total Tows	432	424	+1.9
Singles	22.0%	22.0%	0
Doubles	58.5%	58.5%	0
Setovers & Knockouts	19.4%	19.4%	0
Total Barges	3828	3936	-2.7
Utilization	81.1%	80.2%	+0.9
Auxiliary Chamber			
Total Tows	81	78	+3.9
Singles	59.0%	43.6%	+15.4
Doubles	12.8%	19.2%	- 6.4
Setovers & Knockouts	28.2%	37.2%	- 9.0
Total Barges	267	269	- 0.7
Utilization	8.5%	8.6%**	- 0.1

* Adjusted from 30-day-month values provided by simulation run.

** Utilization by pleasure craft of 0.6% has been subtracted.

Table 9

Recreational and Light Boat Lock Utilization

Month	No. Noncommercial Main	No. Noncommercial Auxiliary	Avg Time Auxiliary min	Total Time Auxiliary min	Percentage of Time Auxiliary
Oct 75	-	40	18.8	752	1.7
Nov 75	1	29	20.8	603	1.4
Dec 75	1	14	20.6	288	0.7
Jan 76	1	18	18.1	326	0.7
Feb 76	3	17	16.9	287	0.7
Mar 76	1	20	18.9	378	0.9
Apr 76	2	42	18.6	781	1.8
May 76	-	51	20.3	1035	2.3
Jun 76	-	52	21.1	1097	2.5
Jul 76	3	127	20.9	2654	6.0
Aug 76	11	49	21.3	1044	2.3
Sep 76	1	76	23.1	1756	4.1
				Avg	2.1

Table 10

Actual and Estimated Monthly Tonnages at Gallipolis Locks and Dam

Month	Average Monthly Percentage*	Actual 1972 kt**	Actual 1974 kt**	Actual 1976 kt**	Projected Monthly Tonnages, kt† 1978	1980	1982	1984	1986	1988	1990	1991
Jan	8.1	2,739	2,559	3,097	3,718	4,277	4,617	4,965	5,330	5,694	6,059	6,245
Feb	7.9	2,791	2,759	3,402	3,626	4,171	4,503	4,843	5,198	5,554	5,909	6,091
Mar	9.0	3,170	3,315	3,902	4,131	4,752	5,130	5,517	5,922	6,327	6,732	6,939
Apr	8.6	3,036	3,214	3,357	3,947	4,540	4,902	5,272	5,659	6,046	6,433	6,631
May	9.2	3,111	3,654	3,708	4,223	4,858	5,244	5,639	6,054	6,467	6,882	7,093
Jun	8.4	2,841	3,153	3,397	3,856	4,435	4,788	5,149	5,527	5,905	6,283	6,476
Jul	7.3	2,666	2,656	2,981	3,351	3,854	4,161	4,475	4,803	5,132	5,460	5,628
Aug	7.9	2,874	3,023	3,158	3,626	4,171	4,503	4,843	5,198	5,554	5,909	6,091
Sep	8.3	2,454	3,204	3,603	3,810	4,383	4,731	5,088	5,461	5,835	6,208	6,399
Oct	8.6	3,057	3,546	3,774	3,947	4,541	4,902	5,272	5,659	6,046	6,433	6,631
Nov	8.0	2,988	2,921	3,342	3,672	4,224	4,560	4,904	5,264	5,624	5,984	6,168
Dec	8.7	2,688	2,866	3,209	3,993	4,594	4,959	5,333	5,725	6,116	6,508	6,708
	TOTAL	34,415	36,870	40,929	45,900	52,800	57,000	61,300	65,800	70,300	74,800	77,100

* Average monthly percentages based on 1971-1976 commodity tonnage movements.

** Lockmaster's unofficial records. Tonnages officially reported by the towing industry to the Waterborne Commerce Statistics Center (WCSC), New Orleans, Louisiana, are shown for the years 1972, 1974, and 1976 in Table 11.

† Tonnage projections beyond 1980 are based on extensions of historical data and highly probable increases through 1980.

Table 11

Gallipolis Commodity Projections*

Description		1972	1974	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Group 1:	Coal	12.4	13.7	16.7	21.2	22.6	25.2	25.7	26.1	26.6	27.0	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5	32.0
	Up	6.7	7.6	11.3	14.2	15.5	18.0	18.5	18.8	19.3	19.7	20.1	20.6	21.1	21.5	22.0	22.4	22.9	23.3	23.8	24.2
	Down	5.7	6.1	5.4	7.0	7.1	7.2	7.2	7.3	7.3	7.3	7.4	7.4	7.4	7.5	7.5	7.6	7.6	7.7	7.7	7.8
Group 2:	Chemicals	4.2	3.6	4.1	4.3	4.7	4.9	5.2	5.4	5.8	6.2	6.4	6.7	6.9	7.2	7.4	7.7	7.9	8.2	8.4	8.7
	Up	3.3	2.8	3.3	3.4	3.8	3.9	4.2	4.3	4.6	4.9	5.0	5.2	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8
	Down	0.9	0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9
Group 3:	Aggregates**	1.6	1.5	1.6	1.6	1.7	1.8	1.9	1.9	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
	Up	1.4	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.6	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6
	Down	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Group 4:	Petroleum	6.2	8.5	7.9	8.5	9.1	9.8	10.5	11.1	11.8	12.4	13.0	13.7	14.4	15.1	15.8	16.5	17.2	17.9	18.6	19.3
	Up	6.0	8.1	7.6	8.2	8.7	9.4	10.1	10.7	11.3	11.9	12.5	13.1	13.8	14.5	15.1	15.8	16.5	17.1	17.8	18.5
	Down	0.2	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8
Group 5:	Metals, Ores, Etc.	4.4	4.4	4.9	5.3	5.6	6.1	6.6	7.0	7.4	7.8	8.2	8.6	9.0	9.4	9.8	10.2	10.6	11.0	11.4	11.8
	Up	2.0	1.8	2.2	2.3	2.5	2.7	3.0	3.2	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.5
	Down	2.4	2.6	2.7	3.0	3.1	3.4	3.6	3.8	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5.9	6.1	6.3
Group 6:	Other**	1.2	1.1	1.7	2.0	2.2	2.6	2.9	3.2	3.5	3.8	4.1	4.4	4.7	5.0	5.3	5.6	5.9	6.2	6.5	6.8
	Up	1.1	1.0	1.4	1.5	1.7	2.0	2.3	2.6	2.8	3.1	3.3	3.6	3.8	4.1	4.4	4.6	4.9	5.2	5.4	5.7
	Down	0.1	0.1	0.3	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.1
Total:	All Commodities	30.0	32.8	36.9	42.9	45.9	50.4	52.8	54.7	57.0	59.2	61.3	63.6	65.8	68.1	70.3	72.6	74.8	77.1	79.3	81.6
	Up	20.5	22.5	27.1	30.9	33.6	37.5	39.7	41.2	42.9	44.7	46.3	48.2	50.1	52.0	53.9	55.7	57.7	59.5	61.4	63.3
	Down	9.5	10.3	9.8	12.0	12.3	12.9	13.1	13.5	14.1	14.5	15.0	15.4	15.7	16.1	16.4	16.9	17.1	17.6	17.9	18.3

NOTE: Tonnages in the first three columns (1972, 1974, and 1976) reported to the Waterborne Commerce Statistics Center (WCSC), New Orleans, Louisiana, by the towing industry.

* Tonnages for the period 1982-1993 are based on extensions of the 1976-1981 trend; all figures are in megatons.

** Tonnages have been adjusted to remove Lime from Group 3 and place it under Group 6, as requested by the sponsor.

Table 12

WATSIM Output Data for Three Alternative Operating Policies

at Current Lockage Facility

(Simulated Lock Operating Time = 30 Days)

	1 Up-1 Down			3 Up-3 Down			FIFO Unrestricted		
Year	Monthly Delay hr	Monthly Tonnage kt	Utilization %	Monthly Delay hr	Monthly Tonnage kt	Utilization %	Monthly Delay hr	Monthly Tonnage kt	Utilization %
1972	665	2,974	40.3	--	--	--	619	2,974	39.8
1974	--	--	--	--	--	--	911	3,194	44.0
1976	1,245	3,434	46.8	--	--	--	1,346	3,434	47.4
1978	3,731	4,370	65.7	--	--	--	3,537	4,345	65.8
1980	7,516	4,719	72.2	--	--	--	8,634	4,790	72.9
1982	15,431	5,212	82.1	--	--	--	16,217	5,262	82.5
1983	--	--	--	18,157	5,312	83.03	--	--	--
1984	17,057	5,522	90.08	22,480	5,365	88.36	17,036	5,567	90.0
1985	--	--	--	--	--	--	18,025	5,976	93.1
1986	21,833	5,996	96.49	Infinite Queuing			20,055*	5,875*	95.81*
1988	Infinite Queuing			--	--	--	--	--	--
1990	--	--	--	--	--	--	--	--	--
1992	--	--	--	--	--	--	--	--	--
1993	--	--	--	--	--	--	--	--	--

* Extrapolated values obtained by multiplying pertinent output at sample time 38,880 min by 1.2. Infinite queuing occurred for maximum queue length of 30 tows at time 40,622 min.

Table 13

Present Fleet and Lockage Facility

Theoretical Maximum Tonnages, 1 Up-1 Down Operating Policy

Year (Run No.)	Chamber	(1) Tows/ Lockage	(2) Avg Lockage Time min	(3) Maximum Lockages/ Month 43,200 ÷ (2)	(4) Tons/ Barge	(5) Barges/ Tow	(6) Barges/ Lockage (1) × (5)	(7) Tons/ Lockage (4) × (6)	(8) Theoretical Maximum Tons/Month, 10^6 (3) × (7)	(9) Theoretical Maximum Tons/Year, 10^6 (8) × 10.75
1972 (9M01G1U72)	Main	0.6070	50.024	864	863	8.71	5.29	4,565	3.9442	42.4
	Aux	0.9107	35.500	1,217	863	2.71	2.47	2,132	2.5946	27.9
									6.5488	70.3
1976 (17M01G1U76)	Main	0.6073	50.720	852	869	8.77	5.33	4,632	3.9465	42.4
	Aux	0.8440	37.174	1,162	869	3.32	2.80	2,433	2.8271	30.4
									6.7736	72.8
1978 (11M01G1U78)	Main	0.5685	51.045	846	793	9.67	5.50	4,362	3.6903	39.7
	Aux	0.6522	40.789	1,059	793	4.83	3.15	2,498	2.6454	28.4
									6.3357	68.1
1980 (12M01G1U80)	Main	0.5663	51.932	832	804	9.79	5.54	4,454	3.7057	39.8
	Aux	0.6149	40.759	1,060	804	5.12	3.15	2,533	2.6850	28.9
									6.3907	68.7
1982 (13M01G1U82)	Main	0.5505	53.097	814	791	10.24	5.64	4,461	3.6313	39.0
	Aux	0.5442	40.301	1,072	791	5.83	3.17	2,508	2.6886	28.9
									6.3199	67.9
1984 (18M01G1U84)	Main	0.5565	52.785	818	783	9.68	5.39	4,220	3.4520	37.1
	Aux	0.5245	39.924	1,082	783	6.38	3.35	2,623	2.8381	30.5
									6.2901	67.6
1986 (19M01G1U86)	Main	0.5654	53.131	813	807	9.67	5.47	4,414	3.5886	38.6
	Aux	0.4989	40.156	1,076	807	6.44	3.21	2,590	2.7868	30.0
									6.3754	68.6

Table 14

Present Fleet and Lockage Facility

Theoretical Maximum Tonnages, 3 Up-3 Down Operating Policy

Year (Run No.)	Chamber	(1) Tows/ Lockage	(2) Avg Lockage Time min	(3) Maximum Lockages/ Month 43,200 ÷ (2)	(4) Tons/ Barge	(5) Barges/ Tow	(6) Barges/ Lockage (1) × (5)	(7) Tons/ Lockage (4) × (6)	(8) Theoretical Maximum Tons/Month, 10^6 (3) × (7)	(9) Theoretical Maximum Tons/Year, 10^6 (8) × 10.75
1983	Main	0.5609	51.310	842	816	9.87	5.54	4,521	3.8067	40.92
(2M01G3U83)	Aux	0.5358	38.953	1,109	816	5.94	3.18	2,595	2.8779	30.94
									6.6846	71.86
1984	Main	0.5637	51.305	842	784	9.83	5.54	4,343	3.6568	39.31
(4M01G3U84)	Aux	0.5104	39.435	1,095	784	6.25	3.19	2,500	2.7375	29.43
									6.3943	68.74

Table 15

Present Fleet and Lockage Facility

Theoretical Maximum Tonnages, FIFO Unrestricted Operating Policy

Year (Run No.)	Chamber	(1) Tows/ Lockage	(2) Avg Lockage Time min	(3) Maximum Lockages/ Month 43,200 ÷ (2)	(4) Tons/ Barge	(5) Barges/ Tow	(6) Barges/ Lockage (1) × (5)	(7) Tons/ Lockage (4) × (6)	(8) Theoretical Maximum Tons/Month, 10^6 (3) × (7)	(9) Theoretical Maximum Tons/Year, 10^6 (8) × 10.75
1972	Main	0.6086	49.088	880	863	8.68	5.28	4,557	4.0102	43.1
(4M01GFU72)	Aux	0.9091	35.491	1,217	863	2.78	2.53	2,183	2.6567	28.6
									6.6669	71.7
1976	Main	0.6050	50.690	852	869	8.82	5.34	4,640	3.9533	42.5
(10M01GFU76)	Aux	0.8421	38.412	1,125	869	3.33	2.80	2,433	2.7371	29.4
									6.6904	71.9
1980	Main	0.5604	50.757	851	811	9.97	5.59	4,534	3.8584	41.5
(7M01GFU80)	Aux	0.6195	40.998	1,054	811	5.08	3.18	2,578	2.7172	29.2
									6.5756	70.7
1985	Main	0.5467	51.095	846	825	10.06	5.50	4,538	3.8392	41.3
(2M01GFU85)	Aux	0.5167	39.459	1,095	825	6.17	3.19	2,632	2.8820	31.0
									6.7212	72.3

Table 16

Interference of Main Chamber Operations with Auxiliary Chamber Operations

(Entry Channel Blockages During December 1975)

Lockage Type	Direction of Lockage	Processing Time	Time Blocked Approach	Percentage of Time
		Upper Approach		
Double	Up	13,680	8,266	60.4
	Down	12,779	9,043	70.8
Single	Up	1,243	163	13.1
	Down	2,913	1,225	42.1
Setover	Up	3,077	1,036	33.7
	Down	658	243	36.9
Knockout	Up	1,645	361	21.9
	Down	745	335	45.0
Jackknife	Up	65	3	4.6
Multivessel	Down	39	1	2.6
	Total	36,844	20,676	56.1
		Lower Approach		
Double	Up	13,680	9,631	70.4
	Down	12,779	7,545	59.0
Single	Up	1,243	437	35.2
	Down	2,913	373	12.8
Setover	Up	3,077	1,166	37.9
	Down	658	209	31.8
Knockout	Up	1,645	686	41.7
	Down	745	161	21.6
Jackknife	Up	65	36	55.4
Multivessel	Down	39	6	15.4
	Total	36,844	20,250	55.0

Table 17

Comparison of Three Operating Policies for the Existing Gallipolis Locks and Dam

Operating Policy	Cumulative Lock Utilization Percent					Total Delay,* 10^3 hr			Tonnage Capacity Limitation megatons/month			Adjusted Annual Practical Tonnage Capacity†† megatons/year	
	1972	1976	1980	1984	1986	Monthly Maximum	Annual High	Annual Most Likely	Theoretical Maximum**	Simulated Maximum†	Adjusted Practical Maximum††	High	Most Likely
1 Up-1 Down	40.3	46.8	72.2	90.1	96.5	5.2	62.4	56.9	6.38	6.00	4.02	48.2	43.2
3 Up-3 Down	--	--	--	88.4	Infinite Queuing	‡	‡	‡	6.39	≈6.00	‡	‡	‡
FIFO Unrestricted	39.8	47.4	72.9	90.0	95.8	5.05	60.6	54.3	6.72	5.88	4.03	48.4	43.3

* Obtained from Delay versus Utilization Curves (Figures 5 and 8) with delay corresponding to 70 percent utilization (95 percent in main chamber and 45 percent in auxiliary chamber). Maximum monthly delays were multiplied by 12.0 and 10.75 to obtain the high and most likely annual delays, respectively.

** Obtained from Tables 13-15.

† Obtained from Table 12. The simulated maximum tonnage shown for 3U3D was approximated. Simulated maximum tonnages correspond to impractical high utilization of the auxiliary chamber.

†† Obtained from plots of Tonnage versus Utilization (Figures 4 and 7) with tonnage corresponding to 70 percent utilization (95 percent in main chamber and 45 percent in auxiliary chamber). Tonnage levels were adjusted to correspond to commodity movements reported to the Waterborne Commerce Statistics Center (WCSC) by the shipping industry. Monthly practical maximum tonnages were multiplied by 12.0 and 10.75 to obtain high and most likely annual practical tonnage capacities, respectively.

‡ Insufficient data to construct plot of Tonnage versus Utilization for the 3 Up-3 Down Operating Policy. Limited simulation runs for 3 Up-3 Down indicate this policy to be less desirable than either 1 Up-1 Down or FIFO Unrestricted for both tonnage capacity and total delay.

Table 18

Reductions in Chamber Processing Times for Switchboat Operations and Associated Minor Structural Improvements

Type of Lockage	Time for Main Chamber min Up	Time for Main Chamber min Down	Time for Auxiliary Chamber min Up	Time for Auxiliary Chamber min Down
Double Lockages				
Extraction of unpowered cut by switchboat	7.4	13.0	5.0	8.0
Elimination of recoupling at lock	14.4	11.7	13.3	11.3
Total time savings	21.8	23.7	18.3	19.3
Setover Lockages				
Elimination of recoupling at lock	22.1	12.7	14.8	15.0
Attaching switchboat for assistance in traveling to the mooring area (estimated time)	-3.0	-3.0	-3.0	-3.0
Total time savings	19.1	9.7	11.8	12.0
Knockout Lockages				
Elimination of recoupling at lock	7.0	7.0	5.0	5.1
Attaching switchboat for assistance in traveling to the mooring area (estimated time)	-3.0	-3.0	-3.0	-3.0
Total time savings	4.0	4.0	2.0	2.1
Summarized Time Reductions Used in the WATSIM Model				
Double Lockages	22	24	18	19
Setover & Knockout Lockages (weighted average)	11	5	7	6

Table 19

Difference in Average Turnback Exit Times of Single Lockage Tows and Average Turnback Exit Times for Doubles, Setovers, and Knockouts, Up Direction, Main Chamber

Month (1)	Turnback Exit Times, min: Singles (2)	Turnback Exit Times, min: Doubles (3)	Difference Between (3)&(2) (4)	Setover Turnback Exit Times (5)	Difference Between (5)&(2) (6)	Knockout Turnback Exit Times (7)	Difference Between (7)&(2) (8)
Oct 75	3.3	18.3	15.0	18.8	15.5	9.5	6.2
Nov	3.3	18.3	15.0	23.7	20.4	8.8	5.5
Dec	3.7	18.2	14.5	24.1	20.4	10.6	6.9
Jan 76	4.6	22.8	18.2	32.9	28.3	15.3	10.7
Feb	3.8	18.5	14.7	33.3	29.5	12.8	9.0
Mar	2.9	19.1	16.2	23.3	20.4	9.4	6.5
Apr	2.7	15.4	12.7	38.7	36.0	10.1	7.4
May	4.5	16.0	11.5	26.6	22.1	8.4	3.9
Jun	4.3	16.1	11.8	21.4	17.1	7.8	3.5
Jul	3.7	17.3	13.6	21.3	17.6	12.2	8.5
Aug	5.0	19.8	14.8	18.5	13.5	8.5	3.5
Sep	5.5	19.2	13.7	24.8	19.3	10.0	4.5
Avg			14.3		21.7		6.3

Table 20

Difference in Average Exchange Exit Times of Single Lockage Tows and Average Exchange Exit Times for Doubles, Setovers, and Knockouts, Up Direction, Main Chamber

Month (1)	Exchange Exit Times, min Singles (2)	Exchange Exit Times, min Doubles (3)	Difference Between (3)&(2) (4)	Setover Exchange Exit Times (5)	Difference Between (5)&(2) (6)	Knockout Exchange Exit Times (7)	Difference Between (7)&(2) (8)
Oct 75	6.8	22.3	15.5	22.2	15.4	14.4	7.6
Nov	7.7	21.9	14.2	25.0	17.3	15.6	7.9
Dec	6.8	21.7	14.9	31.2	24.4	16.3	9.5
Jan 76	8.3	21.7	13.4	34.5	26.2	17.8	9.5
Feb	6.6	23.2	16.6	35.4	28.8	16.9	10.3
Mar	10.3	21.8	11.5	30.2	19.9	15.8	5.5
Apr	6.1	21.3	15.2	31.9	25.8	14.5	8.4
May	6.8	22.2	15.4	32.7	25.9	13.1	6.3
Jun	6.5	20.9	14.4	30.2	23.7	16.0	9.5
Jul	7.6	20.8	13.2	29.0	21.4	13.6	6.0
Aug	7.6	22.7	15.1	27.0	19.4	14.1	6.5
Sep	7.8	22.9	15.1	28.1	20.3	13.3	5.5
Avg			14.5		22.4		7.7

Table 21

Difference in Average Turnback Exit Times of Single Lockage Tows and Average Turnback Exit Times for Doubles, Setovers, and Knockouts, Down Direction, Main Chamber

Month	Turnback Exit Times, min		Difference Between (3)&(2)	Setover Turnback Exit Times	Difference Between (5)&(2)	Knockout Turnback Exit Times	Difference Between (7)&(2)
	Singles	Doubles					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Oct 75	3.6	13.8	9.9	8.0	4.4	10.5	6.9
Nov	3.2	16.0	12.8	14.7	11.5	11.0	7.8
Dec	3.0	14.9	11.9	6.5 {2}*	3.5	10.3 {3}	7.3
Jan 76	4.0	17.4	13.4	24.0 {1}	20.0	9.5	5.5
Feb	4.1	16.5	12.4	22.0 {4}	17.9	10.7	6.6
Mar	4.7	13.1	8.4	--	--	10.5	5.8
Apr	3.8	14.3	10.5	11.0 {1}	7.2	7.8 {4}	4.0
May	4.8	14.4	9.6	--	--	10.7 {3}	5.9
Jun	4.6	15.6	11.0	15.3 {3}	10.7	10.3	5.7
Jul	3.0	16.4	13.4	18.3 {3}	15.3	9.0	6.0
Aug	5.1	15.6	10.5	--	--	10.5 {4}	5.4
Sep	1.8	17.4	15.6	8.0 {1}	6.2	10.5 {4}	8.7
Avg			11.6		10.7		6.3

* Numbers in braces indicate sample size.

Table 22

Difference in Average Exchange Exit Times of Single Lockage Tows and Average Exchange Exit Times for Doubles, Setovers, and Knockouts, Down Direction, Main Chamber

Month (1)	Exchange Exit Times, min: Singles (2)	Exchange Exit Times, min: Doubles (3)	Difference Between (3)&(2) (4)	Setover Exchange Exit Times (5)	Difference Between (5)&(2) (6)	Knockout Exchange Exit Times (7)	Difference Between (7)&(2) (8)
Oct 75	8.1	19.1	11.0	22.5	14.4	13.4	5.3
Nov	8.5	19.7	11.2	21.6	13.1	13.1	4.6
Dec	7.3	19.9	12.6	32.4	25.1	17.7	10.4
Jan 76	7.6	23.2	15.6	--	--	14.8	7.2
Feb	7.4	19.4	12.0	11.8 {4}*	4.4	11.8	4.4
Mar	7.4	18.7	11.3	20.5 {4}	13.1	13.4	6.0
Apr	7.5	18.6	11.1	30.0 {3}	22.5	13.7	6.2
May	7.2	18.7	11.5	26.5 {4}	19.3	14.0	6.8
Jun	7.4	18.7	11.3	13.0 {1}	5.6	14.4	7.0
Jul	7.5	17.3	9.8	15.0 {3}	7.5	13.4	5.9
Aug	6.8	18.8	12.0	27.0 {3}	20.2	27.3 {4}	20.5
Sep	7.6	20.0	12.4	24.0 {3}	16.4	14.3	6.7
Avg			11.8		14.7		7.6

* Numbers in braces indicate sample size.

Table 23

Difference in Average Fly Exit Times of Single Lockage Tows and Average Fly Exit Times for Doubles, Setovers, and Knockouts, Up Direction, Auxiliary Chamber

Month (1)	Fly Exit Times, min Singles (2)	Doubles (3)	Difference Between (3)&(2) (4)	Setover Fly Exit Times (5)	Difference Between (5)&(2) (6)	Knockout Fly Exit Times (7)	Difference Between (7)&(2) (8)
Oct 75	2.4	8.0	5.6	16.8	14.4	4.3	1.9
Nov	2.2	19.0	16.8	16.3	14.1	13.3	11.1
Dec	2.1	16.8	14.7	8.4	6.3	9.4	7.3
Jan 76	2.4	14.5	12.1	24.0	21.6	5.0	2.6
Feb	2.2	15.0	12.8	18.3	16.1	7.5	5.3
Mar	12.2	21.1	8.9	20.0	7.8	6.6	5.6
Apr	2.5	10.5	8.0	16.7	14.2	6.7	4.2
May	2.9	19.8	16.9	22.1	19.2	7.6	4.7
Jun	2.0	14.3	12.3	28.5	26.5	5.8	3.8
Jul	2.9	15.7	12.8	15.2	12.3	7.8	4.9
Aug	2.8	22.5	19.7	16.0	13.2	6.6	3.8
Sep	2.5	21.4	18.9	14.4	11.9	7.0	4.5
Avg			13.3		14.8		5.0

Table 24

Difference in Average Fly Exit Times of Single Lockage Tows and Average Fly Exit Times for Doubles, Setovers, and Knockouts, Down Direction, Auxiliary Chamber

Month	Fly Exit Times, min		Difference Between (3)&(2)	Setover Fly Exit Times	Difference Between (5)&(2)	Knockout Fly Exit Times	Difference Between (7)&(2)
	Singles	Doubles					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Oct 75	2.4	11.8	9.4	10.0	7.4	6.1	3.7
Nov	2.3	14.1	11.8	17.0 {4}*	14.7	8.1	5.8
Dec	2.0	16.2	14.2	13.3	11.3	6.8 {4}	4.8
Jan 76	2.1	12.6	10.5	--	--	7.0 {4}	4.9
Feb	2.7	11.3	8.6	27.0 {4}	24.3	6.0 {1}	3.3
Mar	5.5	14.9	9.4	9.6	4.1	5.1	-0.4
Apr**	--	--	--	--	--	--	--
May	2.2	18.2	16.0	20.6	18.4	7.7	5.5
Jun	2.3	12.8	10.5	18.2	15.9	7.4	5.1
Jul	2.5	9.0 {2}	6.5	18.4	15.9	10.1	7.6
Aug	2.6	22.0 {2}	19.4	26.7 {3}	24.1	7.7	5.1
Sep	2.7	10.8	8.1	16.7	14.0	7.5	4.8
Avg			11.3		15.0		5.1

* Numbers in braces indicate sample size.

** Average fly exit time of singles during April 1976 was unrealistically high and therefore it was eliminated from the above data.

Table 25

WATSIM Output Data for Three Alternate Operating Policies

with Switchboat Operations in the Upper Pool Only

(Simulated Lock Operating Time = 30 Days)

	1 Up-1 Down			4 Up-4 Down			FIFO Unrestricted		
Year	Monthly Delay hr	Monthly Tonnage kt	Utilization %	Monthly Delay hr	Monthly Tonnage kt	Utilization %	Monthly Delay hr	Monthly Tonnage kt	Utilization %
1972	415	2,986	36.6	476	2,986	36.8	413	2,986	36.5
1976	900	3,448	42.0	1,260	3,434	42.8	885	3,448	41.8
1980	4,549	4,738	64.0	8,149	4,696	64.6	4,138	4,914	64.6
1984	14,164	5,434	81.2	18,609	5,372	82.2	14,466	5,601	80.8
1986	17,148	5,974	88.1	27,919	5,869	90.5	18,192	6,147	88.5
1988	18,093	6,295	92.0	27,947	6,123	93.6	18,545	6,439	92.2
1990	32,029	6,558	98.2		Infinite Queuing		32,280	6,507	98.1
1991		Infinite Queuing						Infinite Queuing	

Table 26

Comparison of Three Operating Policies Using Switchboats in the Upper Pool Only at Gallipolis Locks and Dam

	Cumulative Lock Utilization Percent						Total Delay,* 10^3 hr			Tonnage Capacity Limitations Adjusted megatons/month			Adjusted Annual Practical Tonnage Capacity†† megatons/year	
Operating Policy	1972	1976	1980	1984	1988	1990	Monthly Max	Annual High	Annual Most Likely	Theoretical Max**	Simulated Max†	Adjusted Practical Max††	High	Most Likely
1 Up-1 Down	36.6	42.0	64.0	81.2	92.0	98.2	7.2	86.4	77.4	6.93	6.56	4.59	55.1	49.3
4 Up-4 Down	36.8	42.8	64.6	82.2	93.6	Infinite Queuing	10.2	122.4	109.7	7.05	6.12	4.47	53.6	48.1
FIFO Unrestricted	36.5	41.8	64.6	80.8	92.2	98.1	7.2	86.4	77.4	6.97	6.51	4.67	56.0	50.2

* Obtained from Delay versus Utilization Curves (Figures 16 and 19) with delay corresponding to 75 percent utilization (95 percent in main chamber and 55 percent in auxiliary cnamber). Minimum monthly delays were multiplied by 12.0 and 10.75 to obtain the high and most likely annual delay, respectively.

** Obtained from Tables 32-34.

† Obtained from Table 25.

†† Obtained from Tonnage versus Utilization Curves (Figures 15 and 18) with tonnage corresponding to 75 percent utilization (95 percent in main chamber and 55 percent in auxiliary chamber). Tonnage levels were adjusted to correspond to commodity movements reported to the Waterborne Commerce Statistics Center (WCSC) by the shipping industry. Monthly practical maximum tonnages were multiplied by 12.0 and 10.75 to obtain the high and most likely annual practical tonnage capacities, respectively.

Table 27

WASIM Output Data for Three Alternate Operating Policies with Switchboat Operations in the Upper and Lower Pools*

(Simulated Lock Operating Time = 30 Days)

	1 Up-1 Down			4 Up-4 Down			FIFO Unrestricted		
Year	Monthly Delay hr	Monthly Tonnage kt	Utilization %	Monthly Delay hr	Monthly Tonnage kt	Utilization %	Monthly Delay hr	Monthly Tonnage kt	Utilization %
1972	291	2,986	32.9	303	2,986	33.0	277	2,986	32.8
1976	599	3,427	37.9	739	3,427	38.7	618	3,427	37.8
1980	2,797	4,936	57.6	4,610	4,803	57.5	2,607	4,966	56.9
1984	6,860	5,450	69.4	15,539	5,392	72.3	7,884	5,610	70.1
1986	10,680	5,934	76.8	20,493	5,922	80.0	10,749	6,055	76.3
1988	14,776	6,229	81.4	21,279	6,297	83.6	15,680	6,350	80.4
1990	21,151	6,800	89.8	32,983	6,699	91.9	22,154	6,791	91.1
1992	26,282	7,445	97.2	Infinite Queuing			24,422	7,473	96.8

* This table is also applicable to switchboat operations in the upper pool and an extended center guard wall in the lower pool.

Table 28

Comparison of Three Operating Policies Using Switchboats in the Upper Pool and Either Switchboats or an Extended Center Guard Wall in the Lower Approach

	Cumulative Lock Utilization Percent						Total Delay,* 10^3 hr			Tonnage Capacity Limitations Adjusted megatons/month			Adjusted Annual Practical Tonnage Capacity†† megatons/year	
Operating Policy	1972	1976	1980	1984	1988	1992	Monthly Max	Annual High	Annual Most Likely	Theoretical Max**	Simulated Max†	Adjusted Practical Max††	High	Most Likely
1 Up-1 Down	32.9	37.9	57.6	69.4	81.4	97.2	11.5	138.0	123.6	7.90	7.45	5.44	65.3	58.5
4 Up-4 Down	33.0	38.7	57.5	72.3	83.6	Infinite Queuing	18.9	226.0	203.2	7.92	6.70	5.26	63.1	56.5
FIFO Unrestricted	32.8	37.8	56.9	70.1	80.4	96.8	11.5	138.0	123.6	8.19	7.47	5.51	66.1	59.2

* Obtained from Delay versus Utilization Curves (Figures 22 and 25) with delay corresponding to 80 percent utilization (95 percent in main chamber and 64 percent in auxiliary chamber). Maximum monthly delays were multiplied by 12.0 and 10.75 to obtain the high and most likely annual delays, respectively.

** Obtained from Tables 35-37.

† Obtained from Table 27.

†† Obtained from plots of Tonnage versus Utilization (Figures 21 and 24) with tonnage corresponding to 80 percent utilization (95 percent in main chamber and 64 percent in auxiliary chamber). Tonnage levels were adjusted to correspond to commodity movements reported to the Waterborne Commerce Statistics Center (WCSC) by the shipping industry. Monthly practical maximum tonnages were multiplied by 12.0 and 10.75 to obtain the high and most likely annual practical tonnage capacities, respectively.

Table 29

Summary of Capacity Data for Using Switchboats in the Upper Pool and Extending the Lower Landward Guide Wall

Operating Policy	Adjusted Practical Tonnage Capacity* megatons			Total Delay,** 10^3 hr		
	Monthly Max	Annual High	Annual Most Likely	Monthly Max	Annual High	Annual Most Likely
1 Up-1 Down	5.15	61.8	55.36	8.0	96.0	86.0
4 Up-4 Down	4.99	59.88	53.64	12.8	153.6	137.6
FIFO Unrestricted	5.21	62.52	56.01	8.0	96.0	86.0

* Obtained from plots of tonnage versus utilization (Figures 21 and 24) with tonnage corresponding to 75 percent utilization (95 percent in main chamber and 55 percent in auxiliary chamber). Tonnage levels were adjusted to correspond to commodity movements reported to the Waterborne Commerce Statistics Center (WCSC) by the shipping industry. Monthly practical maximum tonnages were multiplied by 12.0 and 10.75 to obtain the high and most likely annual practical tonnage capacities, respectively.

** Obtained from delay versus utilization curves (Figures 22 and 25) with delay corresponding to 75 percent utilization (95 percent in main chamber and 55 percent in auxiliary chamber). Maximum monthly delays were multiplied by 12.0 and 10.75 to obtain the high and most likely annual delays, respectively.

Table 30

WATSIM Output Data, FIFO Ready-to-Serve Operating Policy (Simulated Lock Operating Time = 30 Days)

Year	Monthly Delay hr	Monthly Tonnage kt	Utilization %
1972	321	2,986	33.4
1974	472	3,208	37.0
1976	605	3,434	38.0
1978	1,425	4,403	50.2
1980	2,163	4,973	55.1
1982	3,543	5,326	62.5
1984	5,634	5,697	69.1
1986	6,978	6,123	74.5
1988	12,341	6,386	78.4
1990	21,443	6,692	89.1
1992	27,492	7,473	98.2
1993		Infinite Queuing	

Table 31

Summary of Capacity Data for the FIFO Ready-to-Serve Operating Policy

Operating Policy	Cumulative Lock Utilization Percent						Total Delay,* 10^3 hr			Tonnage Capacity Limitations megatons/month			Adjusted Annual Practical Tonnage Capacity†† megatons/year	
	1972	1976	1980	1984	1988	1992	Monthly Max	Annual High	Annual Most Likely	Theoretical Max**	Simulated Max†	Adjusted Practical Max††	High	Most Likely
FIFO Ready-to-Serve	33.4	38.0	55.1	69.1	78.4	98.2	15.3	183.6	164.5	7.78	7.47	5.89	70.7	63.32

* Obtained from delay versus utilization curve (Figure 29) with delay corresponding to 85 percent utilization (95 percent in main chamber and 76 percent in auxiliary chamber). Maximum monthly delays were multiplied by 12.0 and 10.75 to obtain the high and most likely annual delays, respectively.

** Obtained from Table 38.

† Obtained from Table 30.

†† Obtained from plot of tonnage versus utilization (Figure 28) with tonnage corresponding to 85 percent utilization (95 percent in main chamber and 76 percent in auxiliary chamber). Tonnage levels were adjusted to correspond to commodity movements reported to the Waterborne Commerce Statistics Center (WCSC) by the shipping industry. Monthly practical maximum tonnages were multiplied by 12.0 and 10.75 to obtain the high and most likely annual practical tonnage capacities, respectively.

Table 32

Switchboat Operations in the Upper Pool

Theoretical Maximum Tonnages, 1 Up-1 Down Operating Policy

Year (Run No.)	Chamber	(1) Tows/ Lockage	(2) Avg Lockage Time min	(3) Maximum Lockages/ Month 43,200 ÷ (2)	(4) Tons/ Barge	(5) Barges/ Tow	(6) Barges/ Lockage (1) × (5)	(7) Tons/ Lockage (4) × (6)	(8) Theoretical Maximum Tons/Month, 10^6 (3) × (7)	(9) Theoretical Maximum Tons/Year, 10^6 (8) × 10.75
1972	Main	0.6098	44.782	965	863	8.67	5.29	4565	4.4052	47.4
(1M02G1U72)	Aux	1.0000	32.522	1328	863	2.52	2.52	2175	2.8884	31.1
									7.2936	78.5
1976	Main	0.6136	44.879	962	871	8.63	5.30	4616	4.4406	47.7
(2M02G1U76)	Aux	0.9059	35.988	1200	871	3.05	2.76	2404	2.8848	31.1
									7.3254	78.8
1980	Main	0.5822	46.523	929	804	9.54	5.55	4462	4.1452	44.6
(3M02G1U80)	Aux	0.6533	37.040	1166	804	4.79	3.13	2517	2.9348	31.5
									7.0800	76.1
1984	Main	0.5574	47.710	905	772	9.68	5.40	4169	3.7720	40.6
(4M02G1U84)	Aux	0.5664	37.762	1144	772	5.94	3.36	2594	2.9675	31.9
									6.7395	72.5
1988	Main	0.5552	47.542	909	818	9.85	5.47	4474	4.0669	43.7
(6M02G1U88)	Aux	0.5264	37.401	1155	818	5.86	3.09	2528	2.9198	31.4
									6.9867	75.1
1990	Main	0.5499	48.280	895	791	9.71	5.34	4224	3.7805	40.6
(7M02G1U90)	Aux	0.4790	34.910	1238	791	6.73	3.22	2547	3.1532	33.9
									6.9337	74.5

Table 33

Switchboat Operations in the Upper Pool

Theoretical Maximum Tonnages, 4 Up-4 Down Operating Policy

Year (Run No.)	Chamber	(1) Tows/ Lockage	(2) Avg Lockage Time min	(3) Maximum Lockages/ Month 43,200 ÷ (2)	(4) Tons/ Barge	(5) Barges/ Tow	(6) Barges/ Lockage (1) × (5)	(7) Tons/ Lockage (4) × (6)	(8) Theoretical Maximum Tons/Month, 10^6 (3) × (7)	(9) Theoretical Maximum Tons/Year, 10^6 (8) × 10.75
1972	Main	0.6073	44.772	965	854	8.77	5.33	4552	4.3927	47.2
(1M02G4U72)	Aux	1.0000	32.268	1339	854	2.49	2.49	2126	2.8467	30.6
									7.2394	77.8
1976	Main	0.6118	44.984	960	869	8.69	5.32	4623	4.4381	47.7
(2M02G4U76)	Aux	0.8660	35.598	1214	869	3.20	2.77	2407	2.9221	31.4
									7.3602	79.1
1980	Main	0.5880	45.127	957	802	9.49	5.58	4475	4.2826	46.0
(3M02G4U80)	Aux	0.6474	37.094	1165	802	4.70	3.04	2438	2.8403	30.5
									7.1229	76.5
1984	Main	0.5729	45.913	941	770	9.60	5.50	4235	3.9851	42.8
(4M02G4U84)	Aux	0.5415	37.053	1166	770	5.97	3.23	2487	2.8998	31.2
									6.8849	74.0
1988	Main	0.5626	47.050	918	808	9.65	5.43	4387	4.0273	43.3
(6M02G4U88)	Aux	0.5181	36.847	1172	808	6.15	3.19	2578	3.0214	32.5
									7.0487	75.8

Table 34

Switchboat Operations in the Upper Pool

Theoretical Maximum Tonnages, FIFO Unrestricted

Year (Run No.)	Chamber	(1) Tows/Lockage	(2) Avg Lockage Time min	(3) Maximum Lockages/Month 43,200 : (2)	(4) Tons/Barge	(5) Barges/Tow	(6) Barges/Lockage (1) × (5)	(7) Tons/Lockage (4) × (6)	(8) Theoretical Maximum Tons/Month, 10^6 (3) × (7)	(9) Theoretical Maximum Tons/Year, 10^6 (8) × 10.75
1972 (1M02GFU72)	Main	0.6038	44.502	971	863	8.66	5.23	4514	4.3831	47.1
	Aux	0.9787	33.936	1273	863	2.61	2.55	2201	2.8019	30.1
									7.1850	77.2
1976 (2M02GFU76)	Main	0.6092	44.672	967	870	8.74	5.32	4628	4.4753	48.1
	Aux	0.9043	34.234	1262	870	2.99	2.70	2349	2.9644	31.9
									7.4397	80.0
1980 (3M02GFU80)	Main	0.5816	45.077	958	818	9.66	5.62	4597	4.4039	47.3
	Aux	0.6677	37.383	1156	818	4.69	3.13	2560	2.9594	31.8
									7.3633	79.1
1984 (4M02GFU84)	Main	0.5524	45.482	950	797	9.86	5.45	4344	4.1268	44.4
	Aux	0.5741	37.562	1150	797	5.67	3.26	2598	2.9877	32.1
									7.1145	76.5
1988 (6M02GFU88)	Main	0.5527	45.715	945	833	9.83	5.43	4523	4.2742	45.9
	Aux	0.5220	36.882	1171	833	5.92	3.09	2574	3.0142	32.4
									7.2884	78.3
1990 (7M02GFU90)	Main	0.5512	45.814	943	782	9.80	5.40	4223	3.9823	42.8
	Aux	0.4899	36.774	1175	782	6.64	3.25	2542	2.9869	32.1
									6.9692	74.9

Table 35

Switchboat Operations in the Upper and Lower Pools*

Theoretical Maximum Tonnages, 1 Up-1 Down Operating Policy

Year (Run No.)	Chamber	(1) Tows/ Lockage	(2) Avg Lockage Time min	(3) Maximum Lockages/ Month 43,200 ÷ (2)	(4) Tons/ Barge	(5) Barges/ Tow	(6) Barges/ Lockage (1) × (5)	(7) Tons/ Lockage (4) × (6)	(8) Theoretical Maximum Tons/Month, 10^6 (3) × (7)	(9) Theoretical Maximum Tons/Year, 10^6 (8) × 10.75
1972	Main	0.6110	39.948	1081	863	8.63	5.27	4548	4.9164	52.9
(1M03G1U72)	Aux	1.0000	32.727	1320	863	2.55	2.55	2201	2.9053	31.2
									7.8217	84.1
1976	Main	0.6144	40.470	1067	868	8.63	5.30	4600	4.9082	52.8
(2M03G1U76)	Aux	0.9730	34.270	1261	868	2.65	2.58	2239	2.8234	30.4
									7.7316	83.2
1980	Main	0.5979	41.215	1048	814	9.40	5.62	4575	4.7946	51.5
(3M03G1U80)	Aux	0.7189	34.438	1254	814	4.22	3.03	2466	3.0924	33.2
									7.8870	84.7
1984	Main	0.5689	41.898	1031	782	9.60	5.46	4270	4.4024	47.3
(4M03G1U84)	Aux	0.6362	33.381	1294	782	4.99	3.17	2479	3.2078	34.5
									7.6102	81.8
1988	Main	0.5527	42.184	1024	812	9.83	5.43	4409	4.5148	48.5
(6M03G1U88)	Aux	0.5716	34.312	1259	812	5.25	3.00	2436	3.0669	33.0
									7.5817	81.5
1990	Main	0.5465	41.663	1037	797	9.85	5.38	4238	4.4467	47.8
(7M03G1U90)	Aux	0.5244	34.245	1261	797	6.14	3.22	2566	3.2357	34.8
									7.6824	82.6
1992	Main	0.5509	41.767	1034	807	9.98	5.50	4439	4.5899	49.3
(8M03G1U92)	Aux	0.5082	33.988	1271	807	6.36	3.23	2607	3.3135	35.6
									7.9034	84.9

* These computations are also applicable to the operating policy of switchboat operations in the upper pool and either an extended center guard wall or an extended landward guide wall in the lower pool.

Table 36

Switchboat Operations in the Upper and Lower Pools*

Theoretical Maximum Tonnages, 4 Up-4 Down Operating Policy

Year (Run No.)	Chamber	(1) Tows/ Lockage	(2) Avg Lockage Time min	(3) Maximum Lockages/ Month 43,200 ÷ (2)	(4) Tons/ Barge	(5) Barges/ Tow	(6) Barges/ Lockage (1) × (5)	(7) Tons/ Lockage (4) × (6)	(8) Theoretical Maximum Tons/Month, 10^6 (3) × (7)	(9) Theoretical Maximum Tons/Year, 10^6 (8) × 10.75
1972	Main	0.6116	39.841	1084	863	8.62	5.27	4548	4.9300	53.0
(1M03G4U72)	Aux	1.0000	31.000	1394	863	2.53	2.53	2183	3.0431	32.7
									7.9731	85.7
1976	Main	0.6133	40.596	1064	868	8.64	5.30	4600	4.8944	52.6
(2M03G4U76)	Aux	0.9481	33.546	1288	864	2.70	2.56	2212	2.8491	30.6
									7.7435	83.2
1980	Main	0.6077	40.094	1072	809	9.14	5.55	4490	4.8133	51.7
(3M03G4U80)	Aux	0.6864	33.250	1293	809	4.48	3.08	2492	3.2222	34.6
									8.0355	86.3
1984	Main	0.5773	40.679	1062	774	9.45	5.46	4226	4.4880	48.2
(4M03G4U84)	Aux	0.5956	33.552	1288	774	5.48	3.26	2523	3.2496	34.9
									7.7376	83.1
1988	Main	0.5622	39.932	1082	812	9.70	5.45	4425	4.7879	51.5
(6M03G4U88)	Aux	0.5616	33.911	1274	812	5.47	3.07	2493	3.1761	34.1
									7.9640	85.6
1990	Main	0.5583	40.574	1065	802	9.71	5.42	4347	4.6296	49.8
(7M03G4U90)	Aux	0.5145	33.855	1276	802	6.25	3.22	2582	3.2946	35.4
									7.9242	85.2

* These computations are also applicable to the operating policy of switchboat operations in the upper pool and either an extended center guard wall or an extended landward guide wall in the lower pool.

Table 37

Switchboat Operations in the Upper and Lower Pools*

Theoretical Maximum Tonnages, FIFO Unrestricted

Year (Run No.)	Chamber	(1) Tows/ Lockage	(2) Avg Lockage Time min	(3) Maximum Lockages/ Month 43,200 ÷ (2)	(4) Tons/ Barge	(5) Barges/ Tow	(6) Barges/ Lockage (1) × (5)	(7) Tons/ Lockage (4) × (6)	(8) Theoretical Maximum Tons/Month, 10^6 (3) × (7)	(9) Theoretical Maximum Tons/Year, 10^6 (8) × 10.75
1972	Main	0.6135	39.712	1088	863	8.57	5.26	4539	4.9384	53.1
(1M03GFU72)	Aux	1.0000	32.275	1338	863	2.53	2.53	2183	2.9209	31.4
									7.8593	84.5
1976	Main	0.6144	40.055	1079	868	8.64	5.31	4609	4.9731	53.5
(2M03GFU76)	Aux	0.9863	34.055	1269	868	2.61	2.57	2231	2.8311	30.4
									7.8042	83.9
1980	Main	0.5998	39.990	1080	818	9.36	5.61	4589	4.9561	53.3
(3M03GFU80)	Aux	0.7359	33.507	1289	818	4.11	3.02	2470	3.1838	34.2
									8.1399	87.5
1984	Main	0.5666	40.008	1080	797	9.62	5.45	4344	4.6915	50.4
(4M03GFU84)	Aux	0.6321	33.892	1275	797	5.07	3.20	2550	3.2513	35.0
									7.9428	85.4
1988	Main	0.5519	40.494	1067	830	9.79	5.40	4482	4.7823	51.4
(6M03GFU88)	Aux	0.5782	33.353	1295	830	5.28	3.05	2532	3.2789	35.2
									8.0612	86.6
1990	Main	0.5511	40.332	1071	792	9.85	5.43	4301	4.6064	49.5
(7M03GFU90)	Aux	0.5217	34.306	1259	792	6.17	3.22	2550	3.2105	34.5
									7.8169	84.0
1992	Main	0.5486	39.379	1097	814	9.94	5.45	4436	4.8663	52.3
(8M03GFU92)	Aux	0.5153	34.601	1249	814	6.34	3.27	2662	3.3248	35.7
									8.1911	88.0

* The computations are also applicable to the operating policy of switchboat operations in the upper pool and either an extended center guard wall or an extended landward guide wall in the lower pool.

Table 38

Gallipolis Locks and Dam Capacity Study, Present Fleet

Theoretical Maximum Tonnages, FIFO Ready-to-Serve Operating Policy

Year (Run No.)	Chamber	(1) Tows/ Lockage	(2) Avg Lock-age Time min	(3) Maximum Lockages/ Month 43,200 : (2)	(4) Tons/ Barge	(5) Barges/ Tow	(6) Barges/ Lockage (1) × (5)	(7) Tons/ Lockage (4) × (6)	(8) Theoretical Maximum Tons/Month, 10^6 (3) × (7)	(9) Theoretical Maximum Tons/Year, 10^6 (8) × 10.75
1972 (1M01GFR72)	Main	0.6141	40.542	1066	863	8.56	5.26	4539	4.8386	52.0
	Aux	1.0000	32.690	1322	863	2.54	2.54	2192	2.8978	31.2
									7.7364	83.2
1976 (3M01GFR76)	Main	0.6182	40.187	1075	869	8.56	5.29	4597	4.9418	53.1
	Aux	0.9851	34.612	1248	869	2.56	2.52	2190	2.7331	29.4
									7.6749	82.5
1980 (4M01GFR80)	Main	0.6071	38.458	1123	816	9.25	5.62	4586	5.1501	55.4
	Aux	0.7849	34.952	1236	816	3.67	2.88	2350	2.9046	31.2
									8.0547	86.6
1984 (6M01GFR84)	Main	0.5748	38.031	1136	797	9.54	5.48	4368	4.9621	53.3
	Aux	0.6483	36.048	1198	797	4.86	3.15	2511	3.0082	32.3
									7.9703	85.6
1988 (8M01GFR88)	Main	0.5530	37.900	1140	833	9.74	5.39	4490	5.1186	55.0
	Aux	0.6110	35.961	1201	833	4.96	3.03	2524	3.0313	32.6
									8.1499	87.6
1990 (9M01GFR90)	Main	0.5432	38.091	1140	791	10.08	5.48	4335	4.9419	53.1
	Aux	0.5863	39.250*	1101	791	5.55	3.25	2571	2.8307	30.4
									7.7814	83.5
1992 (9M01GFR90)	Main	0.5397	37.377	1156	814	10.27	5.54	4510	5.2136	56.0
	Aux	0.6028	42.269*	1022	814	5.64	3.40	2768	2.8289	30.4
									8.0425	86.4

* Increase in average lockage time due to greater number of setovers and knockouts using the auxiliary chamber.

Table 39

Processing Times* (Minutes) by Lockage Type at Gallipolis Locks and Dam for Upbound Tows

Lockage Type	Approach Time		Entry Time	Chamber Time	Exit Time		Total Processing Time			
	Exchange	Turnback			Exchange	Turnback	Exchange Approach/ Exchange Exit	Exchange Approach/ Turnback Exit	Turnback Approach/ Turnback Exit	Turnback Approach/ Exchange Exit
Main Chamber										
Singles	12.4	5.5	5.2	13.4	6.9	4.3	37.9	35.3	28.4	31.0
Doubles	20.2	7.8	14.4	63.8**	22.4	18.2	120.8	116.6	104.2	108.4
Setovers	16.4	8.9	18.6	14.0	29.7	24.3	78.7	73.3	65.8	71.2
Knockouts	15.4	5.4	12.8	13.7	15.0	9.3	56.9	51.2	41.2	46.9
Auxiliary Chamber										
Singles	11.8	3.7	3.4	15.5	5.0	2.1	35.7	32.8	24.7	27.6
Doubles	19.1	8.0	12.1	59.8†	21.6	14.4	112.6	105.4	94.3	101.5
Setovers	13.6	5.2	12.1	15.4	21.5	17.2	62.6	58.3	49.9	54.2
Knockouts	16.4	5.4	8.2	15.2	14.6	5.4	54.4	45.2	34.2	43.4

* Average times for the months of Oct and Dec 1975 and Feb, May, and Aug 1976.

** Chambering time of doubles in main chamber = Chamber_1 (14.4) + Turnback Exit_1 (14.6) + Turnback (13.4) + Turnback Approach_2 (1.8) + Entry_2 (5.6) + Chambering_2 (14.0) = 63.8 min.

† Chambering time of doubles in auxiliary chamber = Chamber_1 (15.2) + Turnback Exit_1 (8.5) + Turnback (15.6) + Turnback Approach_2 (1.5) + Entry_2 (3.8) + Chambering_2 (15.2) = 59.8 min.

Table 40

Processing Times* (Minutes) by Lockage Type at Gallipolis Locks and Dam for Downbound Tows

Lockage Type	Approach Time		Entry Time	Chamber Time	Exit Time		Total Processing Time			
	Exchange	Turnback			Exchange	Turnback	Exchange Approach/ Exchange Exit	Exchange Approach/ Turnback Exit	Turnback Approach/ Turnback Exit	Turnback Approach/ Exchange Exit
Main Chamber										
Singles	13.5	5.5	4.5	10.0	7.4	4.1	35.4	32.1	24.1	27.4
Doubles	18.4	9.8	10.6	53.5**	19.2	15.0	101.7	97.5	88.9	93.1
Setovers	15.5	7.9	15.4	10.9	24.1	12.2	65.9	54.0	46.4	58.3
Knockouts	14.8	9.0	10.9	10.5	15.1	10.5	51.3	46.7	40.9	45.5
Auxiliary Chamber										
Singles	7.8	3.2	3.3	13.0	5.7	2.5	29.8	26.6	22.0	25.2
Doubles	15.2	4.8	8.7	54.6†	16.0	14.9	94.5	93.4	83.0	84.1
Setovers	27.8	3.4	12.8	15.2	12.8	16.0	68.6	71.8	47.4	44.2
Knockouts	7.1	4.9	7.4	14.7	12.2	6.7	41.4	35.9	33.7	39.2

* Average times for months of Oct and Dec 1975 and Feb, May, and Aug 1976.

** Chambering time of doubles in main chamber = Chamber_1 (11.9) + Turnback Exit_1 (12.2) + Turnback (10.0) + Turnback Approach_2 (1.4) + Entry_2 (5.0) + Chambering_2 (13.0) = 53.5 min.

† Chambering time of doubles in the auxiliary chamber = Chamber_1 (14.9) + Turnback Exit_1 (7.0) + Turnback (13.2) + Turnback Approach_2 (1.5) + Entry_2 (3.4) + Chambering_2 (14.6) = 54.6 min.

Table 41

Simulated Tow Traffic at Gallipolis Locks and Dam in 1984

Arrival Order (1)	Tow No. (2)	Arrival Time (minutes after time Ø) (3)	Direction (U or D) (4)	Tow Length (5)	Tow Width (6)	No. Barges (7)	Barge Type (8)	Lockage Type* Main Chamber (9)	Lockage Type* Aux Chamber (10)	Selected Chamber (11)	Lockage Order by Chamber (12)
1	115	5057	D	1150	54	4	7	2	>3	Main	1
2	116	5193	D	1030	104	18	1	2	3	Main	2
3	117	5208	U	260	105	3	2	5	1	Aux	1
4	118	5293	U	1150	108	8	7	2	>3	Main	3
5	119	5303	D	260	35	1	3	5	5	Aux	2
6	120	5307	U	240	52	2	1	5	5	Aux	3
7	121	5396	D	730	104	5	5	2	3	Main	4
8	122	5401	D	950	104	8	6	2	>3	Main	5
9	123	5412	D	1125	105	14	2,3	2	>3	Main	6
10	124	5417	D	685	105	8	2,3	6	3	Main	7
11	125	5453	U	450	104	8	1	1	2	Aux	5
12	126	5515	U	450	104	8	1	1	2	Aux	6
13	127	5525	D	700	52	3	5	6	2	Aux	4
14	128	5556	U	455	105	5	2	1	2	Aux	7
15	129	5558	D	1150	54	4	8	2	>3	Main	8
16	130	5559	D	1150	54	4	7	2	>3	Main	9
17	131	5687	D	625	78	9	1	6	2	Aux	10
18	132	5916	U	750	104	8	4	2	3	Main	10
19	133	5984	D	1150	104	9	5	2	>3	Main	14
20	134	5994	D	685	105	9	2,3	2	3	Aux	16

(Continued)

* Lockage types are: 1 - straight single, 2 - straight double, 3 - straight triple, >3 - more than three cuts, 4 - single setover, 5 - multiple lockage, 6 - single knockout.

Table 41 (Concluded)

Arrival Order (1)	Tow No. (2)	Arrival Time (minutes after time Ø) (3)	Direction (U or D) (4)	Tow Length (5)	Tow Width (6)	No. Barges (7)	Barge Type (8)	Lockage Type* Main Chamber (9)	Lockage Type* Aux Chamber (10)	Selected Chamber (11)	Lockage Order by Chamber (12)
21	135	6019	U	215	52	1	4	5	5	Aux	8a
22	136	6038	U	1170	105	16	2,3	2	>3	Main	11
23	137	6064	U	930	105	12	2,3	2	>3	Main	12
24	138	6078	D	1150	54	4	8	2	>3	Main	16
25	139	6117	D	825	104	16	1	2	3	Main	17
26	140	6121	U	1030	104	20	1	2	3	Main	13
27	141	6145	D	685	105	9	2,3	2	3	Aux	17
28	142	6159	U	415	78	6	1	1	2	Aux	9
29	143	6172	U	825	104	16	1	2	3	Aux	15
30	144	6175	U	260	105	3	2	5	1	Aux	11
31	145	6202	U	825	104	16	1	2	3	Aux	18
32	146	6254	D	260	105	3	2,3	5	1	Aux	12
33	147	6315	U	1125	105	14	2,3	2	>3	Main	15
34	148	6322	D	260	105	3	2	5	1	Aux	13
35	149	6528	D	825	104	16	1	2	3	Main	18
36	150	6544	U	750	104	6	5	2	3	Aux	19
37	151	6573	D	1150	108	8	7	2	>3	Main	19
38	152	6575	D	1125	105	15	2,3	2	>3	Main	20
39	153	6608	U	260	35	1	2	5	5	Aux	8b
40	154	6706	D	415	52	4	1	5	6	Aux	14

* Lockage types are: 1 - straight single, 2 - straight double, 3 - straight triple, >3 - more than three cuts, 4 - single setover, 5 - multiple lockage, 6 - single knockout.

Table 42

Tow Approach and Exit Delay Times Caused by Channel Blockage
(Based on the scheduled lockage of a sample randomly selected 40-tow queue and 1984 interarrival times)

Main Chamber				Auxiliary Chamber			
Tow No.	Delay of Approach min	Delay of Exit min	Sub-total	Tow No.	Delay of Approach min	Delay of Exit min	Sub-total
129	10.7	--	10.7	117	--	38.7	38.7
133	--	2.0	2.0	120	--	23.4	23.4
147	--	22.7	22.7	127	--	25.9	25.9
139	71.2	--	71.2	126	13.2	46.9	60.1
149	--	25.9	25.9	128	23.1	--	23.1
151	29.6	25.8	55.4	135 & 153	--	31.9	31.9
152	28.9	--	28.9	142	27.5	--	27.5
		Total	216.8	146	--	31.0	31.0
				148	32.2	60.0	92.2
				154	30.9	55.5	86.4
				141	49.5	--	49.5
				145	70.8	--	70.8
						Total	560.5

Total Locking Period = 38 hr, 45.5 min or 2327.5 min

216.8 ÷ 2327.5 = 0.093 or 9.3% of time main chamber could not be utilized due to approach channel blockage

Main Chamber Utilization = 100.0% - 9.3% = 90.7%

Total Locking Period = 37 hr, 5.5 min or 2225.5 min

560.5 ÷ 2225.5 = 0.252 or 25.2% of time auxiliary chamber could not be utilized due to approach channel blockage

Auxiliary Chamber Utilization = 100.0% - 25.2% = 74.8%

Table 43

Summary of Capacity Data for the Tow Scheduling Policy

Operating Policy	Total Delay,* 10^3 hr Monthly Maximum	Annual High	Annual Most Likely	Adjusted Practical Tonnage Capacity** 10^6 tons Monthly Maximum	Annual High	Annual Most Likely
1 Up-1 Down	12.1	145.2	130.1	4.63	55.6	49.8
FIFO Unrestricted	11.6	139.2	124.7	4.66	55.9	50.1

* Obtained from delay versus utilization curves for present lockage facilities (Figures 5 and 8) with delay corresponding to 83 percent utilization (90.7 percent in main chamber and 74.8 percent in auxiliary chamber). Maximum monthly delays were multiplied by 12.0 and 10.75 to obtain the high and most likely annual delays, respectively.

** Obtained from plots of tonnage versus utilization for present lockage facilities (Figures 4 and 7) with tonnage corresponding to 83 percent utilization (90.1 percent in main chamber and 74.8 percent in auxiliary chamber). Tonnage levels were adjusted to correspond to to commodity movements reported to the Waterborne Commerce Statistics Center (WCSC) by the shipping industry. Monthly practical maximum tonnages were multiplied by 12.0 and 10.75 to obtain the high and most likely annual practical tonnage capacities, respectively.

Table 44

Lockage Component Times--October 1975 Normal Versus February 1976 High Waters

		Main Chamber			Auxiliary Chamber		
Lockage Component	Dir	Normal Flow (Oct 75)	High Flow (Feb 76 >25 ft)*	Difference	Normal Flow (Oct 75)	High Flow (Feb 76 >25 ft)*	Difference
Fly & Exchange Approach	U	18	18	0	12	17	+5
	D	18	21	+3	10	12	+2
Turnback Approach	U	10	6	-4	10	1**	--
	D	12	10	-2	8	2**	--
Chambering Times							
Single	U	17	14	-3	17	17	0
	D	14	15	+1	16	13	-3
Double	U	91	74	-17	79	60	-19
	D	73	65	-8	70	49	-21
Setover & Knockout	U	41	43	+2	32	33	+2
	D	30	26	-4	35	48**	--
Exit	U	5	5	0	2	2	0
	D	6	5	-1	2	4	+2

* High flow conditions are assumed to occur at Gallipolis when the total height of all raised gates in the dam is 25 ft or greater.

** Very small sample size.

Table 45

Total Delays and Tonnage Levels for Aternate Operating Policies

Operating Policy	Most Likely Annual Delay 10^3 hr	Most Likely Annual Practical Tonnage Capacity megatons	Year Lock Capacity Could Be Exceeded*
Existing Gallipolis Lockage Facilities (95% Main Chamber Utilization and 45% Auxiliary Chamber)			
1U1D	55.9	43.2	1978
FIFO Unrestricted	54.3	43.3	1978
Tow Scheduling to Minimize Interference from Operations in an Adjacent Chamber (90.7% Main Chamber Utilization and 74.8% Auxiliary Chamber)			
1U1D	130.1	49.8	1979
FIFO Unrestricted	124.7	50.1	1979
Switchboat Operations in the Upper Pool Only (95% Main Chamber Utilization and 55% Auxiliary Chamber)			
1U1D	77.4	49.3	1979
4U4D	109.7	48.1	1979
FIFO Unrestricted	77.4	50.2	1979
Switchboat Operations in the Upper Pool and an Extended Landward Guide Wall in the Lower Pool (95% Main Chamber Utilization and 55% Auxiliary Chamber)			
1U1D	86.0	55.4	1982
4U4D	137.6	53.6	1981
FIFO Unrestricted	86.0	56.0	1982
Switchboat Operations in the Upper Pool and Either Switchboat Operations or An Extended Center Guard Wall in the Lower Pool (95% Main Chamber Utilization and 64% Auxiliary Chamber)			
1U1D	123.6	58.5	1983
4U4D	203.2	56.5	1982
FIFO, Unrestricted	123.6	59.2	1983
Ready-to-Serve (95% Main Chamber Utilization and 76% Auxiliary Chamber)			
FIFO	164.5	63.3	1985

* Based on projected tonnages shown in Table 11.

APPENDIX A: FILE IDENTIFICATION CODES

1. The data generated by each WATSIM run were stored in permanent files under separate file names. Each file name has been coded to include: (a) run number, (b) commodity projection set number, (c) lock system alternative, (d) fleet characteristics, (e) operating policy, and (f) tonnage year. To be consistent, this is the same file identification coding system developed for the Winfield study. Each file coding system is as follows:

aaaabccdeeff

where

aaaa = Run number. Run numbers were sequentially assigned for each alternative lock operating policy tested.

b = commodity projection set code

- M for the most likely projection set
- H for high projection set, if desired
- L for low projection set, if desired

cc = lock system alternative

- 01 for the existing system of locks
- 02, 03, etc. for possible structural expansions in the future

d = fleet characteristics

- G for currently observed tow makeups at Gallipolis
- F for future fleet characteristics that may make optimum use of new proposed lock sizes

ee = Operating policy code

- FU for FIFO Unrestricted
- FR for FIFO Ready-to-Serve
- 1U for 1 Up-1 Down (flip-flop) Unrestricted
- 3U for 3 Up-3 Down Unrestricted

ff = Tonnage year, e.g., 74 for 1974, 80 for 1980, etc.

APPENDIX B: COMPARISON OF OCTOBER AND DECEMBER 1975 PMS DATA TAKEN AT GALLIPOLIS LOCKS AND DAM

1. Since a portion of the simulation model input data was obtained from the December 1975 PMS data and the remainder from October 1975 data, a comparison of certain statistics for these two separate months was made. The results of this analysis are shown in Tables B1 and B2. The overall conclusion is that there was no significant difference in the lockage data recorded in October and in December. Table B1 presents a comparison of the following items for the subject months:

- a. Percent of total tonnage for each commodity
- b. Percent of empty barges
- c. Average barge load for each barge type
- d. Percent of tonnage by commodity type transported by each barge type (right side of Table B1)

2. Table B1 indicates that in all cases, the differences between the October and the December prototype data were not significant except when very small sample sizes were involved. Note footnotes to Table B1. Table B2 compares the lockage types processed during the two months. There were considerably more lockages during October, but the percentages of total lockages for each type (singles, knockouts, etc.) compare very closely in all cases for the two months.

Table B1

Comparison of Gallipolis October and December 1975 PMS Data
by Commodity and Barge Type Analysis

Comm Group	Percentage of Total Tonnage Oct 75	Dec 75	Difference (Oct-Dec)
10	56.3	54.5	1.8
20	19.5	19.6	-0.1
30	7.8	8.8	-1.0
40	10.0	11.6	-1.6
50	3.6	3.2	0.4
60	1.8	0.9	0.9
70	--	--	--
80	0.2	0.2	0.0
90	0.8	1.2	-0.4

Barge Type	Empties, %		
R	45.3	48.4	-3.1
J	36.3	37.7	-1.4
S	64.0	40.0	24.0*
I	46.2	43.4	2.8
B	50.0	66.7	-16.7*
T	56.0	48.3	7.7*
Z**	100.0	50.0	50.0*

Barge Type	Average Barge Load		
R	895	936	-41.0
J	1,369	1,404	-35.0
S	1,992	2,667	-675.0*
I	2,326	2,273	53.0
B	167	300	133.0*
T	1,940	2,413	-473.0*
Z	--	340	-340.0*

Barge Type	Total Tonnage, %		
R	21.4	20.1	1.3
J	55.1	54.1	1.0
S	0.5	0.7	-0.2
I	20.4	22.7	-2.3
B	0.0	0.0	0.0
T	2.6	2.2	0.4
Z	--	0.1	-0.1

Comm Group	Barge Type	Tonnage of Comm Type, % Oct 75	Dec 75	Difference (Oct-Dec)
10	R	33.2	32.9	0.3
	J	66.7	66.0	0.7
	S	0.1	--	0.1
	I	--	1.0	-1.0
	Z	--	0.1	-0.1
20	J	10.6	11.0	-0.4
	S	1.3	2.5	-1.2†
	I	77.4	77.1	0.3
	T	10.7	9.4	1.3†
30	R	0.3	0.3	0.0
	J	25.7	19.7	6.0
	S	3.3	2.6	0.7
	I	68.3	75.9	-7.6
	T	2.4	1.6	0.8
40	R	5.1	2.1	3.0
	J	94.9	94.6	0.3
	I	--	3.1	--
	B	0.0	0.2	-0.2
50	R	51.5	54.3	-2.8
	J	43.5	37.2	6.3
	T	5.1	7.8	-2.7
	Z	--	0.8	-0.8
60	R	15.2	6.1	9.1††
	J	84.8	93.9	-9.1††
80	J	14.8	--	14.8††
	J	85.2	100.0	-14.8††
90	R	1.9	8.7	-6.8††
	J	85.9	88.4	-2.5††
	I	--	1.2	-1.2††
	B	0.8	--	0.8††
	T	11.5	--	11.5††
	Z	--	1.7	-1.7††

* These barge types had a small number of barges.
** Z stands for barges not classified elsewhere.
† Barge types possibly interchanged or used synonymously.
†† Commodity represents very small percent of total tonnage, <2%.

Table B2

Lockage and Tow Size Analysis Based on Gallipolis October and December 1975 PMS Data

Lockage Type	Total Occurrences of Lockage Type		Percentage of Lockage Type Occurrences	
	Oct 75	Dec 75	Oct 75	Dec 75
Singles	146	127	25	26
Knockouts	70	52	12	10
Setovers	74	56	13	11
Doubles, Double Knockouts, & Setovers	291	261	50	53
Total	581	496	100	100

APPENDIX C: DEFINITIONS

Specialized terms used in this report are defined below:

Chambering. The filling or emptying of the lock chamber with one or more vessels in the chamber.

Chambering time (as defined by the simulation model). The time period beginning when the bow of the vessel being served crosses the sill upon entry to the lock chamber and ending when the stern of the power unit, or towboat, crosses the opposite sill upon exiting the chamber. For multicut lockages and jackknife, knockout, and setover lockages, this time includes the time required to break the tow upon entry to the lock, remake the tow upon exiting, and for processing all intermediate cuts of multicut lockage, including the turnback times.

Cut. That portion of a tow that can be contained within the lock chamber for chambering.

Dedicated equipment. The exclusive use of a towboat and particularly the barges to transport only one type of commodity. The greater the percentage of dedicated equipment, the greater the number of empty backhaul barges.

Double lockage. The lockage of a tow larger than the lock via two distinct lockages.

Double knockout, double setover, or double jackknife lockage. One cut of a double lockage must either be a knockout-, setover-, or jackknife-type lockage in order to permit the passage of the tow in only two lockages. (See definitions of knockout, setover, and jackknife lockages.)

Downstream approach. The reach of river immediately downstream from the lockage facility and dam leading to the lock chamber entrance.

Exchange entry. An entry immediately following the exit of a tow traveling in the opposite direction, whereby an inbound vessel to the chamber passes an outbound vessel.

Exchange exit. This exit type occurs when an outbound vessel passes an inbound vessel traveling in the opposite direction.

Exit time (as defined by the simulation model). The period in minutes beginning when the stern of the exiting towboat crosses the sill on exit and ending when the tow passes the defined approach point or the next entering tow, whichever occurs first.

First In, First Out (FIFO) Unrestricted operating policy. The tows are serviced in the order of their arrival, and no restriction is placed on the barge configuration (tow makeup) or size as they approach the lock; i.e., no remake or reconfiguration of the barges is required prior to beginning the lockage process.

First In, First Out (FIFO) Ready-to-Serve operating policy. Same as the FIFO Unrestricted policy, except it prohibits the breaking or remaking of multicut tows in the vicinity of or within a lock chamber. Setover and knockout lockage types are performed as usual; i.e., they may break and remake at the chamber.

Fleet characteristics. The general makeup of tows in a particular river reach as pertains to boat horsepower, number of barges, barge types and sizes, flotilla configuration, etc.

Fly entry. A fly entry occurs when the lock is idle when an inbound vessel arrives at the lock and is the period of time beginning when the vessel passes the approach point and ending when the vessel's bow crosses the sill upon entering the lock chamber.

Fly exit. A fly exit occurs when the lock will be idle after an outbound vessel departs and is the period of time beginning when the vessel's stern crosses the sill on departure and ending when the vessel passes the approach point.

Guard walls. Guard walls are placed at each end of a lock opposite to the guide walls. The guard walls are aligned to provide flared entrances to the lock and, as the name implies, provide a barrier to guard tows from unintentionally entering areas where hazardous currents exist.

Guide walls. Guide walls are walls that extend outward from each end of the lock chamber and serve as guide structures to aid vessels or tows in aligning for entry into the lock.

Integrated barge. A single unit of barges made up of two or more barges which are usually left connected together to form the integrated barge. A wide variety of barge sizes exists for the barges used in this manner. Most integrated barges are tank barges and are used in a dedicated manner.

Jackknife lockage. The tow is rearranged, e.g., from two barges wide to three, by breaking the face couplings on at least two barges and the side couplings on at least one barge.

Jumbo barge. A regular long Jumbo barge either 195 or 200 ft long and 35 ft wide.

Knockout lockage. The towboat alone is separated from its barges to be "set over" for service.

Lockage. The passage of a vessel through the lock facility.

Lockage component. One of the sequences of events involved in the locking process. These include various types of tow entries, chamberings, and exits.

Lockage types. Lockage types include straight singles, doubles, triples, etc., along with setovers, jackknifes, knockouts, multi-vessel lockages, and others.

Mixed barge tows. A tow consisting of more than one barge type.

Multicut lockage. A lockage requiring two or more straight cuts, e.g., double, triple, quadruple, etc.

Multiple entry. The entry of two or more relatively small tows to be locked together in a single lockage.

Multiple exit. The exit of two or more relatively small tows following their being locked together in a single lockage.

Multiple tow lockage. More than one vessel or tow is served in a single chambering.

Open-pass lockage. The vessel transverses the lock with no lock hardware operation.

Performance Monitoring System (PMS). A system developed by the U. S. Army Corps of Engineers to measure the service which the inland waterways provide to the navigation industry. It has been implemented at Corps' inland navigation facilities within the U. S. and provides planners and operations personnel with data and complete programs needed for analysis of the operation of the inland and intracoastal navigation systems.

Queue. A group of one or more tows waiting to be serviced by the lock.

Regular barge. A small Regular barge 175 ft long and 26 ft wide.

Setover lockage. The towboat and one or more of its barges are separated from the remaining barges to be "set over" for service.

Single lockage. The tow is not broken up for lockage.

Switchboat. A boat permanently stationed at a lock to assist in the locking operations. Such boats serve in a variety of ways, such as extracting unpowered cuts of multicut lockages and transporting them to a mooring area, and enabling double lockage size tows to pass through a lock as two singles.

Turnback. The filling or emptying of the lock chamber required to service the next cut of a multicut lockage tow or another tow traveling in the same direction.

Turnback entry. An entry following a lock turnback during which no vessel was served and in which the vessel to be locked had arrived prior to the exit of the previous vessel being locked.

Turnback exit. This type exit occurs when the next event following it is a lockage in the same direction, which requires that the lock be turned back with no vessels in the chamber.

Tow processing time. The total time in minutes required for a tow to be served by a lock. This time begins when the tow is signaled to enter the lock and ends upon completion of the exit.

Three Up-Three Down operating policy. Three vessels traveling in the same direction are locked sequentially, followed by the sequential lockage of three vessels traveling in the opposite direction or until all vessels in a queue are served, whichever occurs first.

Upstream approach. The reach of the river immediately upstream from the lockage facility and dam leading to the lock chamber entrance.

APPENDIX D: PMS COMMODITY CODES

The following is a list of PMS Commodity Codes.[5*]

Code	Description
01	EMPTY BARGES
10	COAL**
11	Coal and Lignite
20	PETROLEUM AND PETROLEUM PRODUCTS**
21	Crude Petroleum
22	Gasoline
23	Jet Fuel and Kerosene
24	Distillate Fuel Oil
25	Residual Fuel Oil
26	Coke (Coal and Petroleum), Petroleum Pitches, Asphalts, Naphtha, and Solvents
30	CHEMICALS AND RELATED PRODUCTS
31	Organic Industrial Chemicals (Crude Products from Coal Tar, Petroleum, and Natural Gas, Dyes, Organic Pigment, Dyeing and Tanning Materials, Alcohols, Benzene)
32	Synthetics (Plastic Materials, Synthetic Rubber, Synthetic Fiber)
33	Drugs, Soap, Detergent and Cleaning Preparations, Paints, Gum and Wood Chemicals, Radioactive and Associated Materials
34	Inorganic Industrial Chemicals (Sodium Hydroxide)
35	Nitrogenous Chemical Fertilizers (Anhydrous Ammonia)
36	Potassic Chemical Fertilizers
37	Phosphatic Chemical Fertilizers
38	Other Basic Chemicals and Basic Chemical Products
39	Other Fertilizers
40	METALLIC ORES, METAL PRODUCTS (PRIMARY AND FABRICATED), WASTE AND SCRAP MATERIALS**
41	Metallic Ores
42	Iron Ore
43	Primary Iron and Steel Products
44	Other Primary Metal Products
45	Fabricated Metal Products
46	Waste and Scrap Materials

* Reference 5 is listed in the References section at the end of the main body of the report.

** Either not classified within this general category or a more detailed classification is unknown.

Code	Description
50	NONMETALLIC MINERALS, EXCEPT FUELS*
51	Limestone Flux and Calcareous Stone
52	Sand, Gravel, and Crushed Rock
53	Phosphate Rock
54	Sulphur, Liquid and Dry
60	STONE, CLAY, GLASS, AND CONCRETE*
61	Building Cement
62	Lime
70	FRESH FISH AND OTHER MARINE PRODUCTS*
71	Marine Shells, Unmanufactured
80	FARM PRODUCTS*
81	Corn
82	Wheat
83	Soybeans
84	Oats
85	Barley
86	Rye
87	Flaxseed
88	Flour
89	Vegetable Products
90	MISCELLANEOUS PRODUCTS
91	Forest Products
92	Lumber and Wood Products
93	Pulp, Paper, and Allied Products
94	Processed Agricultural Products (including Food and Kindred Products and Tobacco Products)
95	All Manufactured Equipment and Machinery (including Ordinance and Accessories, Machinery, Electrical Machinery, Transportation Equipment, Instruments, Photographic and Optical Goods, Watches and Clocks, and Miscellaneous Products of Manufacturing)
99	COMMODITY IS UNKNOWN OR CANNOT BE LOCATED ON THIS LIST

* Either not classified within this general category or a more detailed classification is unknown.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Daggett, Larry L
Capacity studies of Gallipolis Locks, Ohio River, West Virginia / by Larry L. Daggett, Robert W. McCarley. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va, : available from National Technical Information Service, 1978.
108, [168] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; H-78-6)
Prepared for U. S. Army Engineer District, Huntington, Huntington, West Virginia.
References: p. 108.

1. Gallipolis Locks and Dam. 2. Inland waterways. 3. Lock capacity. 4. Locks (Waterways). 5. Simulation. 6. Tows and towing. I. McCarley, Robert Winton, joint author. II. United States. Army. Corps of Engineers. Huntington District. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; H-78-6.
TA7.W34 no.H-78-6